This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

[illegible] Intro., to the study of [illegible]

BRITISH MUSEUM (NATURAL HISTORY)

CROMWELL ROAD, LONDON, S.W.

MINERAL DEPARTMENT.

AN INTRODUCTION

TO THE

STUDY OF ROCKS.

PRINTED BY ORDER OF THE TRUSTEES.

1895.

H 712

349889

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

PREFACE.

THIS guide-book has been designed on the same general plan as the Introductions to the Study of Meteorites and Minerals, published in 1881 and 1884, respectively. It attempts to give, from a Museum point of view, a simple sketch of the relationships of Rocks, indicating all the more important characters and pointing out their significance.

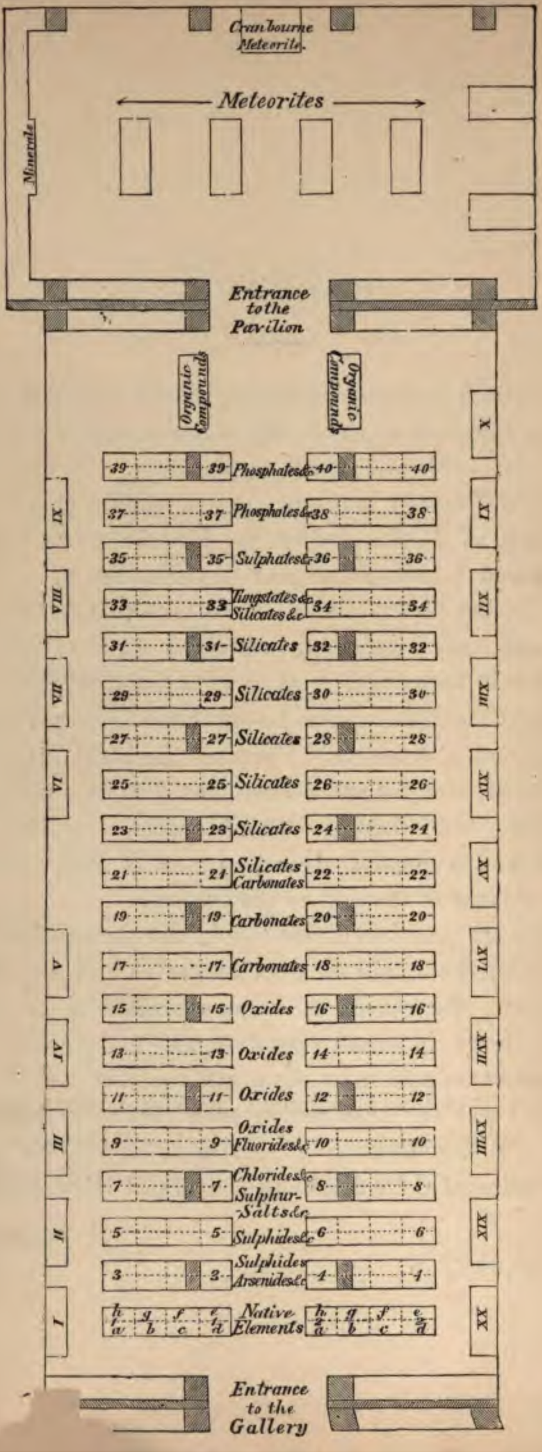
In a perfect Introduction mere speculation would be avoided, and only statements would be made of which the accuracy could be proved, or at any rate suggested, by means of specimens small enough to be exhibited in proper sequence in the cases of a Museum. Further, the ideal Introduction would be brief, and yet not too condensed to be intelligible to every Visitor who, though without special scientific knowledge, has had a general education and is ready to give a moderate amount of thought to the subject.

But there are practical difficulties in the preparation of such a guide-book; the whole of a rock-mass cannot be exhibited in a Museum, the causes of various characters or changes cannot be shown in actual operation, and many rocks require microscopic examination or chemical analysis for their discrimination: yet an Introduction even distantly approaching the ideal will doubtless be of service to those who come to study the Mineral Collections of the Natural History Museum.

L. FLETCHER.

August 12*th*, 1895.

PLAN OF THE MINERAL GALLERY



CONTENTS.

PAGE

The mineral products of Nature 1
Rocks 3
Their various points of interest 4
The mineral species and varieties 7
The mineral products which are apparently simple but really mixtures 9
Crystals, amorphous bodies and irregular aggregates 11
The boundary of a rock 17
The general similarity of characters throughout 18
The existence of petrical individuals 20
The lithical characters of rocks 25
The petrical characters of rocks 48
The distribution of rocks into kinds 54
The selection of characters to be used for the distribution into kinds . 61
Consideration of the more common kinds 63
A preliminary grouping of these kinds 64
Importance of those lithical characters which may possibly be related to the mode of origin of the rock 74
Characters to be emphasised 74
The modes of origin of the above kinds 75
A nearer approximation to a natural system of classification . . 80
Processes by which rocks have been formed and have attained their present characters 83
The modes of origin of basalt and granite 88
The granite, quartz-felsite, rhyolite and obsidian series . . . 94
The gabbro, dolerite, basalt and tachylyte series 95
The position to be assigned to phonolite 98
The allied felspar-less rocks 98
The modes of origin of the crystalline schists 99
The effect of later research on the classification of rocks . . . 100
The most important kinds of rocks 102
The arrangement of the rocks in the cases 113

INDEX 115

THE STUDY OF ROCKS.

A series of illustrative specimens is in course of arrangement in the window-cases of the Mineral Gallery.

The Animal, Vegetable and Mineral Kingdoms.

THE material products of Nature have been assigned to three Kingdoms:—the Animal, the Vegetable and the Mineral: to the two former belong all those material products which are living or have lived, to the latter all those products which have not been endowed with life.

The products which are living or have lived can generally be most conveniently discriminated from those which have not been endowed with life by the presence of organs essential to the nutrition, growth and reproduction of such products.

These material products of Nature may be briefly designated animal, vegetable and mineral products, respectively.

The same material may at different times belong to products assignable to different Kingdoms.

Just as the constituents of a mineral product may become constituents of the material of a living creature, so, conversely, the material of an animal or plant may be transformed, after the cessation of life, into gaseous, liquid or solid matter affording in its structure no evidence whatsoever of the former relationship to life; in fact, the material of the animal or vegetable product has been completely transformed into a product belonging to the Mineral Kingdom. Anthracitic coal, for instance, although a result of alteration of vegetable matter, has lost all the organised structure which characterised that matter, and is to be regarded as one of the mineral products of Nature.

The study of the terrestrial mineral products.

It is practically, or rather, economically possible to obtain a direct knowledge of only those mineral products of the earth itself which are situated within a mile or so beneath its surface; that is to say, within a crust having a thickness which is only one four-thousandth part of the earth's radius: but the detailed investigation of even this limited amount of matter is far too vast for one individual or one science.

The study of the present configuration of the earth's crust is accordingly left to the Geographer, and the historical aspect of the configuration to the Geologist: the Mineralogist deals, not with the earth's configuration, past or present, but with the characters, localities of occurrence, changes and associations of the matter itself, and deduces principles on which to classify the various kinds.

Only solid mineral products are here considered.

The products which occur on a large scale, but are gaseous or liquid at ordinary temperatures (such as air, water, petroleum), are so different in their characters from those which are solid that they are conveniently left for special consideration; indeed, the differences of gaseous or liquid specimens from one another are seldom obvious on mere inspection, and generally require elaborate experiment for their demonstration.

Large mineral masses are often similar throughout.

Solid mineral products, at once of considerable extent and presenting a general similarity of characters throughout, often occur in Nature, as may be inferred from inspection of stone-quarries and sea-cliffs.

They are sometimes of very large dimensions. A mass of granite in the south-east of Ireland, for example, is 68 miles long and from 8 to 15 miles broad, where it comes to the earth's surface: yet the general similarity of characters is such that specimens obtained from one extremity may easily be mistaken for those from the other. Again, the Cleveland dyke is an approximately vertical wall of unknown depth, which comes to the earth's surface in the north of England: it is of small width, generally less than 100 feet, but it can be traced along the surface of the country, or in mine-workings, through a distance of about 90 miles: it is remarkably constant in its characters; the specific gravity, for example, of fresh unaltered fragments from distant parts of the dyke has been found to vary only between 2·765 and 2·788.

The term Rock.

A solid mineral product, which is at once of considerable extent and presents a general similarity of characters throughout, is termed ***Rock;*** conversely, ***Rock*** may be defined as a solid mineral product possessing these two characters.

Some rocks are wanting in firmness.

There are masses of matter, such as sand, gravel or clay, which, as they are solid mineral products of considerable size, similar in characters throughout their extent, are designated by the above term, and yet, owing to their lack of firmness, do not conform to the popular idea of a rock.

Some large masses consist in part of matter having the organised structure of animals or plants.

Some solid material products of Nature, of considerable extent and presenting a general similarity of characters throughout, as shell-limestone and lignite, have not only had an animal or a vegetable origin, but still retain in parts evidence of the organisation of those animals and plants to which some of their characters are due: they may thus, with propriety, be assigned to both the Mineral and Animal, or to both the Mineral and Vegetable Kingdoms, respectively.

Recurrence of the same kind of rock.

Whatever be the circumstances to which the characters of rocks are due, the circumstances are not entirely local in their occurrence; for the same kind of rock may in most cases be found at widely distant places on the earth's surface.

Various points of interest of rocks.

Rocks, as large masses presenting a general similarity of characters throughout and recurring at various localities, are of interest, economic and scientific, from several points of view.

Sometimes a rock is largely quarried for use as a building-stone or roofing-material, or in the paving and repair of roads, or for the manufacture of mill-stones; or it is used for statuary; or it is sawn, or turned, and polished for decorative purposes. Or again, it is useful as a material for the manufacture of bricks, tiles and porcelain; or for the preparation of derivative products, as quicklime and alum, required in commerce; or it is of interest as containing some substance, as gold, which may be advantageously extracted.

Or again, the interest of a rock may belong to the mode of origin or to the epoch of formation, or to the recurrence of the same kind of rock or the same mode of origin at different stages in the earth's history, or to the changes in the rock since its formation, or to the relationships of the mass to rocks of other kinds.

The investigator of rocks determines all their physical and chemical characters, estimates the relative importance of the characters, compares the rocks of different localities, traces their modes of origin and the changes to which they are subject, and names and classifies the various kinds.

Most rocks can be mechanically resolved into simpler matter.

In most rocks, the unaided eye is able to recognise the presence of matter of different kinds.

An illustrative specimen is a fragment of a rock (granite) which occurs at Garve in Ross-shire (Case VI). Mere inspection teaches us that, in this specimen, at least four kinds of matter come together: first, a substance of a white colour with some of its fractured surfaces smooth and plane (felspar); secondly, a substance with a lustre like that of glass, transparent, of a grey colour, and irregular both in shape and fracture (quartz); thirdly, a silvery substance apparently made up of thin smooth leaves (mica); and fourthly, isolated grains having a red colour and occasionally limited by plane faces (garnet). By a process of simple mechanical division, we can thus extract from this kind of rock at least four kinds of substance: and these will prove to be distinct from each other, not only in outward appearance, but in all their manifold properties.

Similarly, by mere mechanical division of the next rock-fragment (porphyritic pitchstone), found in the Isle of Arran, at least two kinds of substance may be isolated (Case VI): one of them is white and presents planes of cleavage (felspar); the other, in which each individual of the first kind is completely enclosed, is of a dark colour, and uncleavable (pitchstone);

on close examination the latter is found to have the general characters of artificial glass.

It will be found that by no amount of mechanical division can any of the above substances be reduced to others having different characters.

Compositeness is sometimes visible only with the aid of the microscope.

Some rocks are really composite, though their true character is not evident to the unaided eye: it may become manifest, however, when an extremely thin slice of the rock is examined with the microscope by transmitted light, especially if the instrument is fitted with a polariser and an analyser.

Some rocks cannot be physically resolved into simpler materials.

Other rocks, as marble and obsidian, are, as far as even the aided eye can detect, simple in material: they cannot be resolved by any known *physical* means into portions of matter differing one from another in their characters.

The mineral products which cannot be physically resolved into simpler materials may be really either simple or mixed.

Of those mineral products which cannot be physically resolved into simpler materials, those which have important characters in common may be said to belong to the same kind. Observation teaches us that two sets of kinds may be formed: one set comprising all kinds in which the product is physically irresoluble, because it is physically simple; the other set all the remaining kinds in which the product, though simple as far as even the aided eye can detect, is inferred to be really a mixture of different materials, as explained below.

First set: **Mineral species.**

In the first set, which is by far the larger, the physically simple mineral products thus said to belong to the same kind can be referred after analysis to the same type of chemical formula: they may be *amorphous*,* and they then present neither characteristic shape nor cleavage, and if transparent, are without disturbing action on transmitted polarised light; but if the contrary be the case, both shape and cleavage can always be referred to an identical or closely related geometrical form. Such natural products are said to belong to the same mineral species or to a group of isomorphous mineral species, and are briefly and conveniently designated *minerals*.

Varieties of mineral species.

Within a single species, there may be considerable variation in those characters (for instance, colour) which are regarded as of subordinate importance, and are treated as of no account in the distribution of mineral products into species. On the other hand, it is sometimes convenient to regard specimens, which belong to the same species and have a subordinate character or group of subordinate characters in common, as constituting a *variety* of the species: sometimes, though rarely, it is found convenient to denote the variety by a special name. For example, some specimens having the specific characters of beryl are remarkable for a peculiar and beautiful green colour, and are highly esteemed as precious stones; it is found convenient to denote the specimens having this colour by a special name (emerald). A special name, however, is merely a matter of convenience: to the different colour-varieties of fluor, for instance, special names have not been given.

---

* *Amorphos*, shapeless.

A crystallised simple mineral product belongs to a definite mineral species.

It is found by experience that any group of simple mineral products which have the same set of principal characters,* and are either naturally limited by plane faces or endowed with directions of cleavage, can be referred to a definite and generally simple type of chemical formula, if the products can be obtained in sufficient quantity for a complete analysis.

Further, it is found that, in the case of a specimen large enough to allow a determination of all its characters, the whole system of characters is such that two or more of them may suffice to indicate the whole assemblage of principal characters, and thus the mineral species to which the specimen belongs.

Hence it is inferred that even where a specimen is of microscopic size, or at any rate too minute to allow a determination of all its characters, uniformity of aspect throughout a section as seen in transmitted common light, together either with uniformity of disturbing action on transmitted polarised light or with rectilinearity of boundary or of cracks, indicate that the specimen is not only a simple mineral product but belongs to a definite mineral species: and it is further inferred from experience with larger specimens that the identification of some of its characters with those of larger specimens, belonging to fully determined species, may be sufficient to indicate the species to which the small specimen itself really belongs.

For example, it may be inferred that a certain microscopic mineral product is specifically simple and probably tourmaline, although the fundamental specific characters of the specimens, namely, the elements of the crystalline form and the type of the chemical formula, are actually indeterminate. If the type of crystalline symmetry, colour, strong pleochroism, optical uniaxality, relative velocity of the ordinarily and extraordinarily refracted rays, are identical with those of determined specimens of tourmaline, and form an assemblage of characters different from that belonging to any other known mineral species, there comes a time when it is possible to infer, with a probability amounting to practical certainty, that the undetermined product is itself tourmaline: the more numerous and independent the coincidences, although they are of only subordinate characters, the more probable the truth of the inference that the fundamental specific characters of the microscopic mineral product are themselves identical with those of tourmaline.

---

* *Introduction to the Study of Minerals.* 6*d.*

SECOND SET: **Mineral products which cannot be physically resolved into simpler material but yet are really mixtures.**

In the other and far smaller set of kinds, it is found that specimens which cannot be resolved by any physical means into matter having different characters, and which occur on a scale permitting of their detailed examination, can be referred after chemical analysis to no definite type of chemical formula. Like the amorphous specimens of the mineral species, they are without either characteristic shape or cleavage; indeed, their form appears to depend, like that of a large mass of fluid, not upon themselves but solely on external bodies: either they have no disturbing action at all on transmitted polarised light, or the action is very ill-defined.

Now, some of these specimens are glassy, others are stony, in aspect. Experiment teaches us that when a crystallised *simple mineral* has been artificially fused and quickly cooled, its physical characters are changed even when no change in the chemical composition can be detected: the cooled product is changed in density, and is often similar in its general characters to ordinary glass, in that it presents a conchoidal fracture, is without crystalline form and cleavage, and if carefully annealed has no disturbing action on transmitted polarised light.

The same is true of the product of the artificial fusion of a mixture of simple minerals *in indefinite proportions;* but in this case the resulting body, though, as far as can be discovered, physically homogeneous in character, can obviously be referred to no definite type of chemical formula.

As, in some cases at least, the natural products which cannot be referred to a definite chemical formula and have the above characters of artificial glass are known to have flowed in a molten state from a volcanic vent, it may be inferred that they, and possibly other products having the above characters, have resulted from the fusion of indefinite mixtures of simple minerals, and in all cases are, though homogeneous in physical behaviour, to be regarded as mere mixtures of simple products in indefinite proportions.

And it is likewise clear that some at least of those natural products, which, though apparently homogeneous, are incapable of reference to a definite type of chemical formula and are without characteristic shape, but instead of being glassy are stony in aspect, and have some action, though ill-defined, on transmitted polarised light, may likewise be really mixtures. Further, they may conceivably consist of extremely minute particles of crystallised matter, either alone or in association with glassy matter. To give a simple instance:—such mixed products of minute crystallised and glassy particles must almost inevitably be formed, if a mass of molten material of no definite type of chemical formula (for example, ordinary lava), just at the point of solidification, is suddenly forced to a cooler place or subjected to a smaller pressure; the growth of finely dispersed minute crystals, whether formed previously or subsequently to this event, is then hindered by the quick passage to a less mobile condition of the matter which surrounds them.

Even when the apparently homogeneous substance is of small dimensions and cannot be isolated in sufficient quantity for a complete examination, the absence of cleavage-cracks and crystalline boundary, and the absence of disturbing action on transmitted polarised light, may be assumed to indicate that we have probably to deal with matter which has passed quickly from the fluid or gelatinous condition to the solid state, and is amorphous; yet the matter may possibly be crystallised according to the cubic system, imperfect in its external development and not endowed with directions of easy cleavage.

Some modes of origin of crystals and amorphous bodies, and of irregular aggregates.

A glance at some known modes of origin of the crystallised and amorphous conditions of matter will be at this point useful, though the actuality of other modes be freely granted.

CRYSTALS.—In order that the particles of a definite chemical compound may disentangle themselves from other matter and arrange themselves to form a crystal, several conditions must be fulfilled:—

1. During the process of solidification, the constituent particles must have *freedom of translation* towards each other, so that, under the influence of the mutual actions, their centres may take definite relative *positions;* for every property of a crystal is the same for lines parallel to the same direction, in general different for lines differing in direction.
2. During the process of solidification, the constituent particles must have *freedom of rotation*, so that, under the influence of the mutual actions, their similar parts may take definite *orientations;* for all parts taken from the interior of a simple crystal are found to be similarly orientated as regards all their characters.
3. The requisite *length of time* must be allowed for the *completion* of these translations and orientations.

Further, that a crystal, once formed, may grow, it must be sufficiently near to particles of the appropriate material, which have freedom of translation and rotation, are allowed time to reach the crystal and to fall into position, and can pass to the solid state.

Such is the case, for example, when a substance passes into the solid state through the slow evaporation of a liquid which has retained it in solution: the slower the evaporation and the more constant the surrounding circumstances, the more perfect is the development of the crystallised solid.

Such is the case, too, when a substance is fused and allowed to slowly cool to a temperature below that of solidification.

AMORPHOUS BODIES.—On the other hand, a definite chemical compound or a mixture of chemical compounds may assume the amorphous condition, if at the epoch of solidification the characters of the substance are such that the motion of the constituent particles towards each other, or their rotation, is in any way hindered.

A. *From a state of fusion.*—When a simple chemical compound or a mixture is fused and allowed to quickly cool, the passage from the liquid state to one in which the translation or rotation of the constituent particles is no longer possible, may be in some cases so sudden that the particles within a region of visible dimensions are not allowed the time necessary for the assumption of the definite positions which characterise the crystallised condition. This is one way of accounting for the fact that the amorphous solid is *like the original fluid* in being without disturbing action on transmitted polarised light. Such a cooled product has the characters of glass : it is homogeneous and continuous ; it is without crystalline form or cleavage ; its fracture is conchoidal.

Some kinds of fused materials assume the glassy condition on solidification more readily than others.

Experiment proves that a substance which yields a glass if allowed to quickly cool, will generally yield a crystallised product if long maintained at a temperature just above that of solidification, and the particles are thus allowed the time and mobility necessary for the due adjustment of their positions.

B. *From a state of jelly.*—Similarly, as in the case of a resin or hydrated silica, a substance may gradually, through loss of matter by slow evaporation, pass from the colloid or gelatinous condition, in which there is no disturbing action on transmitted polarised light, to the solid condition; and possibly owing to the almost complete absence of change of relative position of the remaining particles, there may be only a very slight change of optical character on change of condition of the substance: the slight disturbance of the polarisation of the transmitted light actually observed may conceivably be due to a mere translational change of position of the residual particles, a strain-effect consequent on the removal of the more volatile matter from the interstices of the gelatinous substance; or the disturbance may be due to the passage of the light from material to interspace and from interspace to material within the solidified substance.

IRREGULAR AGGREGATES.—The circumstances may be such that the parts of a solid substance are irregularly aggregated, whether individually crystallised or amorphous.

For example, the mixing of aqueous solutions of a barium salt and a sulphate has for result the formation of barium sulphate, which is almost completely insoluble in water. Unless the solutions are extremely dilute, the formation of visible granules of barium sulphate is almost instantaneous, wherever the two solutions come into contact with each other: the time necessary for the regular arrangement of the numerous particles of which the granules are composed is wanting, the granules themselves are mere aggregates without crystalline form, and falling to the bottom of the vessel yield a still more complex aggregate, difficult to free entirely from entangled portions of the salts which are present in the solution. That under suitable circumstances the particles of barium sulphate are able to arrange themselves as a simple structure consisting of definitely orientated parts is proved by the excellence of the crystals of this same chemical compound met with in Nature as the mineral barytes. And, in fact, crystals of barium sulphate may be artificially prepared, by allowing the solutions of the two salts to diffuse into each other with such extreme slowness that at a given instant their mixture produces very little more barium sulphate than can be retained in solution.

A particle of an irregular aggregate may be either a truly amorphous body, or, what is probably by far the most frequent case, itself an aggregate of minute crystals too small to be separately distinguished with the aid of the highest available magnifying power: or again, it may be composed of both amorphous and crystallised matter.

Globulites and longulites.

Sometimes, dispersed through a transparent amorphous material, small transparent bodies are visible which are likewise without disturbing action on transmitted polarised light, but, although not limited by plane faces, have forms too often recurrent to be regarded as merely accidental: they may be approximately spherical (globulites) or be long and cylindrical (longulites).

These bodies have been sometimes regarded as in a third condition of solid matter intermediate between the crystallised and amorphous, and it has been imagined that each particle of every crystal has at some time passed through the globulitic stage of existence. This suggestion was made by Vogelsang, who attempted to arrive at a knowledge of the making of crystals by prolonging the time of transformation from the fluid to the crystallised condition: in one set of experiments, for instance, he retarded the crystallisation of sulphur from its solution in carbon bisulphide by the addition of Canada balsam.

It is more probable that the globulites obtained in this and similar ways are merely ordinary amorphous bodies, and that they assumed the spherical form, owing to capillarity or surface-tension, while they were liquid or viscous and suspended in other immiscible liquid or viscous matter of approximately the same density. Oil, if suspended in an immiscible liquid of equal density, takes the spherical form; if both the oil-globules and the enclosing liquid or viscous matter could pass into the solid state without regular orientation of the constituent particles we should have a substance with spherical enclosures, and every part would be without disturbing action on transmitted polarised light. In a very viscous material, the form of the enclosed immiscible matter could be not only globular but elongated: on solidification, longulites might then result.

Crystal and glass: perfect and imperfect.

Though a crystal and a glass may be readily distinguished from each other on the large scale, there is often a practical difficulty in their discrimination when the material is of microscopic dimensions: for either a crystal or a glass may present characters not proper to it as a perfectly developed body.

A perfect crystal is limited by plane faces which meet each other in salient, not re-entrant, angles having magnitudes dependent on the material: in every case each physical character is the same, for the same direction, in all lines parallel to each other, generally different for all lines inclined to each other: geometrically, the form of the crystal can be referred to one or other of certain distinct types of symmetry; and for only one group of these types is a perfect crystal singly refractive with respect to light transmitted in every direction: chemically, it can generally be referred to a definite and simple type of formula: usually it is cleavable in various directions and these are always closely related to its shape: it often forms regular growths (twins) with other crystals possessing characters identical with its own.

But so perfect a body is ideal. A crystal reaches visible dimensions by growth from a smaller size; the growth of a crystal requires time, and at any stage the crystal may cease to grow, owing to the exhaustion of appropriate material in its neighbourhood, or to the particles of appropriate material being unable to reach the crystal by reason of a diminution of the fluidity of the matter surrounding the crystal. Temperature, strength of solution and other circumstances will have an influence on the rate of growth at different parts of a crystal: at any epoch it may visibly consist of smaller crystals and show re-entrant angles, or may completely enclose some of the mother-liquor from which the crystals are being deposited.

A perfect glass, again, has no shape characteristic of the kind of material: if the glass has considerable dimensions, the shape depends merely on that of the cavity in which the glass has solidified; if the amount of solidifying liquid is so small that the surface-tension of the liquid is appreciable as compared with the force of gravity, the shape of the body before and after solidification may be spherical. The assemblage of characters of a perfect glass, relative to any line in it, is the same as that relative to any other line in it, parallel or inclined; the substance is thus singly refractive and presents no directions of cleavage: it can generally be referred to no definite type of chemical formula.

But, in terrestrial circumstances, neither a perfect glass nor a perfect crystal can long retain its perfection. It may be suddenly strained and broken by reason of earth-movements, or slowly ground down by tidal action on a sea-shore: it may be corroded by vapours or liquids. Again, long ages after the formation and the breakage of a crystal, a mere fragment may once more find itself in favourable conditions for growth; it may then repair its broken surfaces and take again the outer form of a perfect crystal. Further, it is proved by experiment that a condition of strain so affects the optical characters of a transparent solid that an originally singly refractive body acquires the property of disturbing transmitted polarised light: yet this is the very property upon which we must largely rely for the discrimination of glass and crystal in the microscopic examination of a rock-constituent.

There is indubitable evidence to show that some masses of rock, which now have a considerable action on transmitted polarised light, have acquired this property by slow change from an earlier glassy condition. And seeing that many composite rocks have doubtless consolidated at a much higher temperature than they possess at present, and that the rate of contraction on cooling is known to vary with the nature of the substance, it is remarkable that the optical characters of the mineral constituents of such rocks have not been more largely altered, than they have been, by the resultant and long-continued strains.

The crystallised and amorphous conditions.

We may infer that possibly each particle of a mineral product is either entirely crystallised or entirely amorphous, or consists of a mixture of crystallised and amorphous matter: that the particles which are simple and entirely crystallised always belong to definite mineral species; that the particles, which are without crystalline form or structure and have no disturbing action on transmitted polarised light, may belong either to definite mineral species or be mixtures of two or more species in indefinite proportions. The difficulty of discrimination in any particular case is due only to the imperfectness of our power of investigation.

On the other hand, it has been suggested that every so-called "amorphous" substance may itself consist wholly of irregularly orientated crystals of extremely small size.

The boundary of a rock.

Since observation teaches us that rocks as above defined—that is to say, large masses of solid mineral matter presenting throughout a general similarity of characters—have an actual existence, and further, that the characters of the rocks at different localities are generally not identical, the question immediately suggests itself as to whether every such mass has a definite bounding surface: and, if such be not the case, whether there is regularity or irregularity in the changes of character in different parts of the mass of mineral matter intervening between two different kinds of neighbouring rock; for it is conceivable that the intervening mass, although presenting no general similarity throughout its extent and thus not being *rock* as above defined, may yet show a gradual transition in its characters to one or both of the rocks which it separates from each other.

It is clearly impossible to determine all the characters of a rock-mass before a decision has been arrived at as to what is to be regarded as the termination or boundary of the mass.

The general similarity of characters throughout.

The consideration of this question involves an examination of the large mineral masses met with in Nature, that we may ascertain more precisely what we must understand by "general similarity of characters throughout" if the term rock is to have any practical signification.

(a). *Similarity, not identity.*

The exhibited slab of granite is from a quarry at Shap in Westmoreland: though obviously several kinds of simple mineral enter into its composition, any portion of the slab sufficiently large to include several constituents is almost indistinguishable from any other portion having the same dimensions; yet neither in size nor form nor relative proportion are the mineral constituents at different parts absolutely constant. In short, the various parts of the slab are similar, not identical, in their features.

(b). *Local variations.*

Again, an isolated portion of what must still be regarded as one rock-mass may present a large variation in characters as compared with other parts of the rock having the same dimensions. In illustration of this, another specimen from the same quarry is shown in the case; the dark-coloured patch, though large as compared with the constituents themselves, is so small as compared with the mass of surrounding material showing constant similarity of characters, that the variation must be regarded as trivial in importance and an unessential feature of the rock.

A similarly local difference of aspect is manifested by the next specimen shown in the case: the variation is there due to the inclusion of a fish and cannot be regarded as an essential character of the rock-mass.

(c). *Interruptions.*

Or again, the continuity of a single rock-mass may be partly or completely interrupted, on a small or large scale, by veins, sheets, walls or bosses of mineral matter having characters quite different from those of the rock-mass itself.

Gradual change of characters within a mass.

But in addition to mere local variations and interruptions within a large mass of mineral matter otherwise similar in its characters throughout, a gradual change sometimes extends outwards from such a mass, the change increasing with the distance until a definite surface is reached at which there is a sudden and complete change of characters. Though the part which shows the variation of characters would only be included within the definition of rock, as given above, when the variation within what is to be regarded as a large volume is negligible, yet that which is constant and that which is variable in characters are parts of what may be treated as a single body, even if the single body be necessarily regarded as consisting of more than one kind of rock.

In some cases, for example, we may imagine, rightly or wrongly, that the whole mass was once uniform in its characters and was altered by agents related in some way or other to the surface where the sudden change begins—for instance, by percolating water or by acid vapours which have obtained access to the interior of the mass from that surface: or again, that the circumstances of consolidation of the parts of a single molten mass were so different in different parts as to induce final differences of characters—as in the case of the outer and inner parts of a lava-stream: or again, that material from a single river was deposited gradually in a lake or sea, and in such a way that the characters of the deposit at any spot depended to some extent on the distance of the spot from the place where the river entered the lake or sea—as in the case of a deposit which shows a gradual passage from clay to sand.

The existence of petrical* individuals.

Individuality in the case of animals, plants, and crystals.

Hence we are led to consider whether or not in the case of rocks there is anything closely or remotely analogous to what in animals, plants and even crystals, is called an *individual.* In the Animal and Vegetable Kingdoms, one individual, though similar to, is never absolutely identical in character with another: further, it may, as in the case of a nut with its kernel, shell and husk, consist of parts, each possibly somewhat similar in characters throughout its extent yet widely different from the others: again, during lapse of time, an individual may show an enormous change of characters, as in the change from a caterpillar to a butterfly, or from a seed to a tree. Hence, if a petrical individual exists, it would not be inconsistent with analogy for it to show, even initially, great differences in the characters of widely separated parts and thus to consist of more than a single rock, or for it to be subject to considerable variations in its features as its age increases.

The discussion of this question of individuality necessitates a brief consideration of some of the modes of origin of rock-masses.

Two principal modes of origin of rocks.

There are two principal modes in which existing large masses of mineral matter are known to have acquired their present characters: though others are known, their consideration is not necessary to our immediate purpose.

In one mode, the mass has been expelled from a vent in the earth's crust as a stream of mud or of red-hot lava, which has afterwards become solid: or again, its constituent material has fallen through the air, in a fragmentary condition, as a shower of stones and dust.

In the other mode, particles of solid matter have been carried in suspension by flowing water, and have been gradually deposited at the bottom of a lake or sea: they have thus formed a mass of matter which has gradually increased in thickness, while retaining a more or less horizontal direction for its upper surface.

---

* *Petra,* a rock: *Petrikos,* pertaining to rocks.

Difficulty of recognition of individuality in the case of either of these two modes.

Now although, if petrical individuals exist, a consolidated lava-stream can only be regarded as either a single individual or part of a still larger one, it may be far from presenting throughout a general similarity of characters: its inner and outer parts may show important differences; the one may be compact, the other contain many cavities; the one may be of stony, the other of glassy aspect. But such a lava-stream is generally not an isolated mass, and may long retain continuity with its source which is at some depth within the earth's crust: the lava-stream, the mass in the vent, and the still larger mass below will not only cool with different degrees of rapidity but under enormous differences of pressure; and experience teaches us that the final characters may be reasonably expected to be widely different throughout the mass. But if the individual to which a single lava-stream belongs is to include the larger mass below, which may besides be continually changing in average chemical composition as the stream leaves it, the individual must further be held to include, not only all the other lava-streams due to the same source, but also the ejected fragmentary matter, and ultimately most of the mineral matter in the neighbourhood: further, the individual will be discontinuous, for the fragmentary matter, being often distributed by the wind for hundreds of miles, becomes included in parts of the earth's crust which have had a quite different origin. Again, some parts of the individual would be still fluid, ages after the external parts had become solid.

And, in the case of rocks formed by the deposition of solid matter from a state of suspension in water, there is likewise a difficulty in recognising the existence of a petrical individual. The nature of the suspended matter at any spot, and thus of the deposit in course of formation there, must continually vary more or less with time, for it depends to a large extent on the violence of the inflowing streams and the nature of the superficial mineral matter of the districts over which the immediately antecedent rain-showers have fallen: and, even at a given instant, the suspended matter at different parts of the same sea or lake must vary with the distance from the place of entry of the stream, for the smaller particles remain longer in suspension and are thus carried farther away than the larger. As the smaller and larger particles are generally of different material—the former consisting largely of clayey matter, the result of combined chemical and mechanical action, and the latter consisting largely of fragmentary quartz, almost wholly a result of action of the latter kind—distant parts of the same deposit may be composed of entirely different material, and intervening parts may show a gradual transition from one to the other. Again, as in the previous mode of origin, different parts of the same deposit may become isolated from each other, and the individual will then be incomplete and discontinuous.

Variations of character of rocks during lapse of time.

And not only may there be an original gradual but large variation of character within a single body, but a gradual and large variation may be produced by agents which come into operation long after the epoch of formation of the rock: for example, the intrusion of a large mass of molten matter into a solid mass of constant character throughout, might conceivably effect, through pressure, heat, and the mechanical and chemical action of the accompanying liquids and vapours, large changes of character which would vary in intensity according to the distance from the intruded body, the chemical composition, the capacity for absorption, and the number and extent of the fissures of the disturbed rock.

Some possible causes of local variation.

And in rocks, formed according to either of the modes mentioned above, we may expect to find, not only gradual variations of character through large parts of a single body, but also local variations such as have already been stated to occur: even if the molten lava, as it leaves its source, is initially uniform in composition, during its progress it may tear away, and carry onwards, fragments of the rocks through which the vent has been made, and it may likewise enclose fragmentary matter, which has fallen on the stream from the same or a neighbouring vent, or which was lying in its direction of flow.

A rock-mass, as now existing, is often a mere fragment of the original body.

Some rocks not only manifest a definite arrangement of material in parallel layers, but in the nature of their material are similar to the mud, sand or calcium carbonate, deposited during historical times: further, they enclose the petrified remains of contemporaneous animals and plants. It is inferred that every rock presenting *all* these characters is itself of sedimentary origin and has been deposited in some river, lake or sea: and that the relative ages of such rocks are furnished by the positions of the layers, the lower being in general older than those above them. Again, the immense thickness of these sedimentary rocks, the differences between the fossil remains in different sediments, and the structural differences of the fossil remains from those animals and plants which are known to exist at the present day, suggest that the formation of the sedimentary rocks has been spread over an enormous interval of time.

There are other rocks which are without definite shape of bounding surface and show no arrangement in layers; they are not similar in material to any sedimentary deposit known to have been formed within historical times, but consist of particles which appear to have mostly crystallised in their present relative positions; they contain no fossils; they apparently disturb or completely interrupt the regularity of arrangement of the adjacent sedimentary rocks, which themselves show more or less variation of character near the junction. It is inferred that a rock showing *all* these characters has been intruded in a liquid or viscous condition into previously formed sedimentary deposits: and that the epoch of its intrusion, as measured on the scale of time furnished by the sedimentary rocks, was subsequent to the formation of the most recently deposited rock which shows signs of disturbance and possibly preceded the deposit of the lowest of those rocks above it which do not appear to have been disturbed.

As sedimentary deposits consist wholly of transported material, their existence has for necessary corollary a correspondingly large destruction of pre-existent rock: and it is thus possible that the rock-masses which now exist, however large, are mere fragments of the masses originally formed. Further, the enormous length of time, during which most of the present rocks have been in existence, must have allowed scope for large alteration in their characters; more especially in the case of the older rocks, which have been subjected to the action of percolating water, gases and vapours, during a longer interval of time.

Petrical individuals have rarely, if ever, existed.

Hence, though we must conclude that petrical individuals, closely analogous to those of the Animal and Vegetable Kingdoms or to Crystals, have rarely, if ever, existed, we must be prepared to recognise that adjacent large masses of mineral matter, now quite different from each other in important characters, may possibly be physically connected, or have been connected, by an intervening mass of matter showing transitional characters, and thus be parts of what must be regarded as a single body: and further, that only a comparatively minute and altered residue of what was once a much larger mass may have continued its existence to the present day.

Nomenclature of kinds of rocks.

Any rock-mass in the earth's crust may be definitely indicated by a precise statement of its position and without the use of a special name. Though a name for the individual is sometimes necessary in the Animal Kingdom, and a name for a prominent rock-mass is sometimes useful in geography, a rock-name is only required by the mineralogist for the purpose of indicating the *kind* of rock, not the particular rock-mass itself.

Lithical characters: petrical characters.

Before we can decide as to what rock-masses are to be regarded as being of the same kind and to be denoted by the same name, it is necessary to investigate the various characters which are presented by rocks, and to determine the degrees of importance to be assigned to them.

It will be convenient to first consider those characters which are manifested by rock-fragments of a size so small as to admit of the preservation of the fragments in the cabinets of a museum: such characters may be conveniently distinguished as *lithical,** since they pertain to *stones.* Afterwards mention will be made of the remaining characters, which belong only to large parts of the rock-mass or to the rock-mass itself, and must of necessity be studied in the field: these characters may be termed *petrical,* as pertaining to *rocks.*

A. Lithical characters

(*i.e., characters of small parts of the rock-mass*).

Immediate constituents: imaginary synthesis of a specimen.

A rock-fragment, whether simple or composite in the kind of its material, may be regarded, *for the purpose of descrip-*

---

* *Lithikos*, pertaining to stones.

tion, as made up of smaller portions of matter, which may be arbitrarily chosen and thus have either a real or an imaginary separateness of existence: if the characters and relative position of each of these arbitrarily chosen parts could be defined with precision, it would be possible, in imagination at least, to make an exact synthesis of the specimen.

If the rock-fragment is physically continuous and homogeneous, like glass, the parts into which it can be imagined to be resolved have only an imaginary separateness of existence: if, on the other hand, the rock is visibly composite, those parts into which it is *immediately* and visibly resoluble may be most conveniently chosen as the arbitrary constituents from which such an imaginary synthesis might be effected.

A complete description of each immediate constituent and of its position relative to the adjacent constituents, however, is impracticable: and, for the purpose of description of a rock-fragment, regard can only be had to the more general and salient characters of both the immediate constituents and their assemblage.

The immediate constituents and their assemblage.

The lithical characters of a rock may belong either to the immediate constituents taken individually or to their assemblage.

Among the characters belonging to the *constituents taken individually* are the specific simplicity or compositeness of each immediate constituent; and, in the former case, the crystallised or amorphous condition, the shape, the complete or fragmentary state, the enclosures and the stages of growth of each constituent.

Among the characters belonging to the *assemblage* are the mode of arrangement of the immediate constituents, the fissility, the hardness and kinds of fracture, the degree of coherence, the qualitative and quantitative mineral and chemical composition, the specific gravity and the colour, of the rock.

1. THE CHARACTERS OF THE INDIVIDUAL IMMEDIATE CONSTITUENTS.

The characters of mere fragments of the immediate constituents and their enclosures can be most completely determined, when it is possible, after reduction of a portion of the rock to powder, to collect together those fragments which are homogeneous throughout and are identical in their characters.

With this end in view, one or other, or a combination, of the following methods is adopted :—

a. The mixed fragments are viewed with a simple lens or microscope, and those which appear similar to each other are picked out, one by one.

b. The mixed fragments are immersed in a liquid of which the density is intermediate between the highest and lowest densities of the various constituents: some of the fragments float and others sink in the liquid, and they are thus separated into two sets. By a series of operations with liquids of different densities, those fragments which have a particular density can be collected together and freed from fragments having a different density.

c. The mixed fragments are subjected to the influence of an ordinary magnet or an electro-magnet, and are thus separated into attracted and unattracted material. By a series of operations with magnets of different strengths, those which have the same degree of susceptibility to the magnetic influence are collected together and freed from others characterised by a different degree of susceptibility.

d. The mixed fragments are subjected to the action of a corrosive gas or liquid: those which are least acted upon are thus freed from others which are more readily dissolved or decomposed by the reagent.

Without a mechanical separation of the immediate constituents, various optical and chemical determinations may be made upon them, as seen in a thin transparent section of the rock, by the aid of the microscope.

Simple or mixed nature of an immediate constituent.

An immediate constituent may either be specifically simple, or, though apparently simple, be really a mixture, or again, it may be visibly and essentially a mixture of mineral species.

The mineral species to which rock-constituents generally belong.

In the most general sense of the term, rock-constituents may be said to belong to every mineral species. Some species are worthy of special mention, however, owing to the frequency or plentifulness of the occurrence of constituents belonging to them.

The most frequently and plentifully represented species are calcite, dolomite, quartz, felspars, micas, pyroxenes, amphiboles and olivines.

Other species frequently represented by rock-constituents are hæmatite, ilmenite, limonite; magnetite, chromite, spinel; zircon, rutile; topaz, andalusite, staurolite, cyanite; garnet, idocrase; scapolite; epidote; leucite, nepheline; beryl; kaolinite; talc, serpentine; chlorites; those of the zeolite family; tourmaline; sphene; apatite.

The geometrical, physical and chemical characters of specimens belonging to these species are described in works which treat of simple minerals.

Crystallised or amorphous condition.

If the constituent is specifically simple, it may be either crystallised or amorphous, but is generally the former: if specifically a mixture, it has no characteristic shape, and when apparently simple has frequently the characters of glass. If a glassy constituent is chemically a mixture of silicates, it may be assumed that the glassy character is a result of quick cooling from a state of fusion: some glasses, however, as hyalite, have probably resulted from the slow solidification of a gelatinous body at a comparatively low temperature.

Shape: remains of organisms.

An immediate constituent, if crystallised, may be either complete or incomplete in the development of its faces.

In the former case, it may either have had space and time for complete development and have escaped destructive action since this stage was reached, or, on the other hand, have been broken and afterwards repaired, as in the case of those grains of sandstone which have become once more completed crystals of quartz.

If incomplete, the irregularity of form may be due to the interference of adjacent matter at the time of the original crystallisation: or it may be of later origin, and have resulted from simple fracture or long-continued attrition, or again, from the corrosive action of liquid or gaseous matter in contact with the originally perfectly developed crystal.

Occasionally, an amorphous body is deposited in plane-faced hollows of a true crystal, and is then itself, though accidentally, limited by plane faces.

Further, a constituent may present characters of external form or internal arrangement which indicate that it was formerly an organism; and the observed characters will be of importance as possibly suggesting the habits of the organism and the circumstances of consolidation of the surrounding matrix.

Enclosures in immediate constituents.

When an immediate constituent is examined, it is generally found to be, if not essentially composite, at most only approximately simple, in material: it encloses foreign bodies, solid, liquid or gaseous, which may have assumed their positions and general characters either before or after the epoch of solidification of the immediate constituent itself.

A solid enclosure may either retain the characters which belonged to it at the time of its own solidification or have undergone subsequent alteration: it may have resulted from a molecular change within the enclosing body, as in the case of spherulites in glass; or have been wholly introduced along fissures; or, again, have been produced by the chemical action of a percolating fluid on the adjacent material.

A careful study of the characters of an enclosure and the surrounding material often renders it possible to infer the mode of origin of the enclosure, or the conditions of formation of the immediate constituent, and may throw light on the mode of formation of the rock itself.

(a). *Solid enclosures in immediate constituents.*

If the enclosure is wholly solid, it may be either crystallised or amorphous, and in the latter case may further be glassy in character.

If crystallised, it is generally older than the enclosing constituent, but is sometimes the result of molecular change in an already solidified material.

If glassy, it has in most cases been imprisoned, when still molten, by the solidification of the constituent round it: but, occasionally, enclosed glass is due to the fusion of an enclosure through the subjection of the more difficultly fusible enclosing constituent to a temperature intermediate between the fusing points of the two materials.

If amorphous, but not glassy, it is often the result of alteration of the enclosing body by fluid agents which have travelled along its fissures.

(b). *Liquid enclosures in immediate constituents.*

If the enclosure is liquid, it generally only partially fills the cavity at the ordinary temperature: it may have been enclosed as liquid or vapour at the epoch of solidification of the surrounding matter, or have penetrated to its present position at some later time. The liquid is usually water containing more or less matter in solution; in some cases it is saturated at ordinary temperatures and encloses crystals of soluble salts. Again, it may be liquid carbonic acid, and therefore under great pressure: at a temperature of 13° C., the pressure of the vapour which is in contact with liquid carbonic acid is no less than 49 atmospheres. The presence of liquid carbonic acid indicates that the enclosing body became solid, or at least was sealed up, under great pressure, and presumably therefore at a considerable depth below the earth's surface.

(c). *Gaseous enclosures in immediate constituents.*

If the enclosure is gaseous, the cavity appears to be empty. The cavity may have existed as a vapour-bubble at the time of solidification of the constituent and have contained liquid matter which has since escaped, or it may be of later origin and due to the removal of a solid enclosure from the constituent by a liquid agent.

Stages of growth of immediate constituents.

Stages in the development of a crystal are in some cases indicated by the positions of enclosures, or by differences in the optical characters of the successive envelopes of the nucleal portion. In fact, experiment teaches us that a complete crystal will at any time resume its growth, and a fragmentary crystal repair itself, if placed in circumstances similar to those in which such crystals can be themselves formed. In some sandstones, waterworn grains have resumed their growth, repaired their broken surfaces, and now display the ordinary forms of quartz-crystals, the original grain being in each case still visible as a nucleus; and in other rocks, to which an igneous origin is assigned, crystals of felspar have resumed their growth long after the epoch of solidification of the rock.

2. THE LITHICAL CHARACTERS OF THE ASSEMBLAGE OF IMMEDIATE CONSTITUENTS.

It being impracticable to completely describe the position and characters of every immediate constituent, it becomes necessary to invent a mode of description which will make it possible to briefly specify those peculiarities of general arrangement which have special importance by reason of their mode of origin or their frequency of occurrence. And it is found that owing to the intimate association of the arrangement with various characters of the individual constituents—such as size, crystallised or amorphous condition, complete or fragmentary shape—certain *combinations of characters*, of common occurrence in rocks, can be conveniently designated by a general term.

For these composite characters, two terms are in ordinary use as synonyms, namely, *structure* and *texture:* by some authors, however, the former term (structure) is reserved for use in the description of the mode of arrangement of large portions of a rock-mass. The latter term (texture) is more appropriate when attention is specially directed to the characters of superficial parts, as in the case of a surface of fracture or a polished face; the former, when the idea of a solid, rather than a surface, is involved. When applied to the description of rocks, either term can have only a purely conventional signification, more or less widely different from the original meaning of the word; for the positions and characters of the constituents, and the processes by which those positions and characters are really arrived at, are very different from any which obtain in actual structural or textile operations, and the composite character itself includes in its signification much more than the mere mode of arrangement of the constituents.

STRUCTURE.

(a). *Investigated without the aid of the microscope.*

In the examination of polished surfaces of rocks *with the unaided eye*, several kinds of structure soon attract attention. Of these we may at this point specially mention the following:—

1. The material appears to consist largely of fragmentary constituents, the intervening spaces being filled with matter which appears to be either homogeneous or at least of much finer grain.

The apparent fragments are sometimes simple, sometimes composite, in material; they are not interpenetrant; in most cases their edges are sharp, in some rounded as if by attrition.

This structure has been termed *aggregate.*

2. The material appears to consist of imperfectly developed but almost wholly unbroken crystals in direct contact with each other.

This structure has been termed *crystalline.*

3. The material appears to be homogeneous and without discontinuity, its parts having only an imaginary separateness of existence.

This structure has been termed *homogeneous.*

4. Crystals, more or less completely developed, are dispersed through an apparently homogeneous continuous material.

This structure has been termed *porphyritic.*

The latter kind of structure is well displayed by an Egyptian rock (*antique porphyry*), which was much employed for ornamental purposes by the Ancients, and was called *porphyrites** by them on account of its purple colour. On a polished surface of this rock, the sections of the dispersed white crystals are conspicuously manifest on the purple *ground*: for the purpose of description, the enclosing material, in the case of all rocks showing this variety of structure, is conveniently distinguished from the enclosed crystals by the term *ground-mass.*

(b). *Investigated with the aid of the microscope.*

By the application of the microscope to the examination of thin slices of rocks by transmitted polarised light, the power of analysis is much increased: thus examined, that part of the rock which appears homogeneous to the unassisted eye may prove to be composite; crystals which are apparently simple may prove to enclose foreign matter, solid, liquid or gaseous; and those which appear to be in direct contact may prove to be separated by other matter. The designation of the kind of structure of a rock may thus depend very largely on the kind of examination to which the rock is submitted: and the above distribution of structure into kinds, suggested by the aspects presented by rocks to the unassisted eye, may merely be useful for the description of those aspects, and no other general statement relative to the rocks which present any one of them be possible. In any case, if the kinds of structure are to have any scientific significance, their definition must involve no limitation of the means of observation.

---

* *Porphurites*, like purple.

Such limitation being completely dispensed with, the *aggregate* and *crystalline* kinds of structure may be still retained as having special importance: the shapes and arrangement of the immediate constituents are such that the rock may conceivably have acquired its structure, in the former case, by the cementation or growth of constituents which had assumed their present forms elsewhere; and in the latter case, by the crystallisation of most of its constituents in their present relative positions, though interspersed crystals may conceivably have been formed elsewhere or at a previous time.

The rocks which appear homogeneous if examined with the microscope are so few in number, that it is convenient to lay stress on the glassy character common to most of them, and thus to recognise a distinct kind of structure, termed *vitreous*, contrasting with the crystalline. A rock presenting vitreous structure may be assumed, as already stated, to have been generally formed by the cooling of a molten mass: and in fact, after being destroyed by fusion, the vitreous structure of such a rock may be reproduced by quick cooling of the material.

The *porphyritic* structure naturally presents itself as the only important one intermediate between the apparently crystalline and the apparently homogeneous; for, when rocks are examined without the aid of a microscope, no structure involving a different relation of the apparently crystallised and apparently amorphous matter (for instance, the enclosure of isolated amorphous constituents in a ground-mass of crystallised matter) calls for special attention. But the recognition of vitreous structure as a distinct kind, and the removal of the restriction as to the means of observation, may necessitate the recognition of one or more kinds of structure intermediate between the crystalline and the vitreous, while the porphyritic structure may lose its former significance. In fact, the general heterogeneity and the differences of structure of the ground-mass of different porphyritic rocks being demonstrated by the aid of the microscope, it becomes necessary to regard the porphyritic structure as merely dependent on differences of size and development of the immediate constituents; and more convenient to regard it, when very pronounced, as a special variety of some other kind of structure, than as a distinct kind of structure itself.

When a porphyritic rock has resulted from the cooling of a molten mass, the difference of development of the porphyritic crystals and the constituents of the ground-mass, both as regards size and shape, points distinctly to a sudden change of the conditions after the porphyritic crystals had been formed; or, again, to the porphyritic crystals having been the least fusible constituents of a pre-existent rock which has been after its solidification again partially melted and again crystallised.

Though almost every glassy rock contains crystals dispersed through it, the structure of all such rocks may be regarded as essentially vitreous; but as belonging to its porphyritic variety when attention is to be specially called to the presence or large size of the crystallised enclosures.

If the glassy constituents are subordinate to those which are crystallised, the structure may be conveniently designated *mero-crystalline* *; the terms hemi- or semi-crystalline are unsatisfactory, since they suggest that only half of the material is crystallised, whereas in general by far the greater portion is in that condition: in this case the term crystalline, used above for the second kind of structure, may be changed to *holo-crystalline.** The simple term *crystalline*, thus set free, is employed by some petrologists to indicate both the holo-crystalline and mero-crystalline kinds, and thus the structure of any rock of which the immediate constituents are either wholly or in great part crystallised; this use of the term, however, sometimes involves an undesirable ambiguity.

---

* *Meros*, a part: *Holos*, whole.

Oolitic or pisolitic structure.

A kind of structure, termed *oolitic* or *pisolitic,*[*] is met with in certain rock-masses, such as limestone and iron-ores, each of which consists essentially of a single kind of mineral: the rock is in great part composed of small spherules, the spaces between them being filled with the same kind of material. The spherules themselves may show both a radiate and a concentric structure. Though, sometimes at least, a result of concretion round a foreign nucleus, oölitic structure is often of organic origin.

Of the aggregate, the holo-crystalline, the mero-crystalline, and the vitreous structures, several varieties are recognised :—

1. *Varieties of aggregate structure.*

(*a.*) If a rock consists chiefly of what appear to be *aggregated fragments,* the variety of structure is termed *fragmental* or *clastic.*[†]

If the fragments have sharp edges the structure is said to be *brecciate,* and the rock a *breccia.*[‡] Such constituents, if true fragments, must either have acquired their forms in the immediate neighbourhood or have been transported by a process involving little friction, for instance, by moving ice-sheets. It is unlikely that the transportation of sharp-edged fragments from a distance by icebergs would be on such a scale as to produce a rock-mass.

Enormous showers of fragmentary, sometimes very minute, material are seen to fall during volcanic outbursts: owing to the vast amount of accompanying steam and the consequent heavy rain-showers in the neighbourhood, the ejected fine material is soon changed to mud and the whole is cemented together into a compact mass. The fragments are termed

---

[*] *Oon,* egg: *Lithos,* stone: *Pisos,* pea.

[†] *Klastos,* broken in pieces.

[‡] *Breccia,* an Italian name.

volcanic lapilli [*] and *volcanic dust;* the rock itself is in general called a *volcanic agglomerate,* and more particularly a *volcanic breccia* or *volcanic tuff,* [†] according as the fragments are mostly large or mostly small in their dimensions. Sometimes a mass of lava, after being shot out from the vent in a viscous condition, takes a round form while spinning in its passage through the air; such a product is termed a *volcanic bomb.*

As regards the nature of their material, the fragmentary constituents of a volcanic agglomerate are identical in their characters either with the materials of adjacent lava-streams or with those of the rocks through which the vent has been made.

A breccia may also be produced by the crushing of a rock owing to earth-movements, the fragments being afterwards cemented together: in such a breccia, parts recognisable as having belonged to the same fragment of the original mass may be expected to be occasionally found in close proximity to one another.

The rock is said to have a *conglomerate structure,* and the rock itself to be a *conglomerate,* if the edges of the fragments are rounded: the name is generally applied to rocks of which the fragmentary constituents have considerable size. If the cemented fragments are chiefly small particles of quartz-sand, the rock is called a *sandstone:* the constituents may represent any stage of the transition from sharp-edged fragments to well-rounded grains.

Desert-sand, of which the motion is due to the wind, is much less angular than sea-sand, of which the motion is chiefly due to the tides: for a given velocity, a moving sand-grain has less frictional effect in water than in air, since a completely immersed sand-grain displaces more than a third of its weight of water and is buoyed up to that extent, while the amount of friction is proportional to the pressure between the rubbing bodies: also, for a given pressure the friction is less when the surfaces in contact are wet. A sandstone derived from desert-sand may thus be expected to consist of particles less angular than the constituents of a similar rock derived from sea-sand.

[*] *Lapilli,* small stones.

[†] *Tufo* or *tufa,* Italian names.

Further, as mentioned later, a fragmental rock may have *flow-structure*, and have once been in the state of mud.

(*b.*) Aggregate structure is not always due to the aggregation of *fragments:* for example, the immediate constituents of a rock may conceivably have been chemically precipitated and have been deposited after long suspension in water. In general, the constituent particles of a pure clay have not been broken from large pieces of the same material, but are the result of a chemical alteration of the felspathic constituents of a pre-existent rock.

A coherent fragmental rock, having once been a loosely aggregated mass, shows in addition to its coarser constituent fragments a finer *cementing* material, which may be of chiefly mechanical or chiefly chemical origin.

The cement is not the same in composition for all sandstones: firmly coherent sandstone of which the cement is siliceous, and the grains are somewhat coarse and sharp, has been termed *grit.*

An aggregated rock may thus show any structure intermediate between that of a mass of loose large or small fragments, that of a mass of fragments cemented together by aggregated material of finer grain, and that of a mass wholly consisting of aggregated fine particles.

2. *Varieties of holo-crystalline structure.*

If the immediate constituents of a holo-crystalline rock are separately visible to the naked eye, the structure may be *coarsely* or *finely crystalline:* if they are only visible with the aid of the microscope, the structure is *micro-crystalline.*

Four important varieties of holo-crystalline structure have been designated by special names, crystalline-granular, pegmatic, ophitic and foliate, respectively.

a. The structure is termed *crystalline-granular,* if the immediate constituents are not very different from each other in size; if they are approximately equally developed on every side, the structure is further distinguished as *granitoid*.

The crystallised constituents have forms such as might result from *mutual interference* during their growth.

b. The structure of a holo-crystalline rock is said to be *pegmatic*,* when in various portions of the rock-mass two different kinds of crystallised mineral are inter-grown in such a way that all parts of each mineral in any one of these portions have the same crystallographic orientation; in section a single crystal of the one appears to include isolated patches of a single crystal of the other: as the patches have often straight edges and a parallel arrangement, they present a rude likeness to written (Hebrew) letters, whence a variety of granite, conspicuously showing an intergrowth of quartz and felspar of this kind, has been called *graphic granite*. The structure, when present, at once attracts attention if a thin rock-section is examined with an analyser by transmitted polarised light, for in the section one mineral is continuous and is uniform in colour, while the other is in enclosed patches, all of the same colour but different from the first.

For such an intergrowth, a *simultaneous* crystallisation of the two minerals is generally necessary.

c. The structure of a holo-crystalline rock is said to be *ophitic*, when the crystallisation of the constituents is such that a crystal of one kind of mineral encloses several crystals of another important constituent in positions which have no definite relation either to each other or to that of the enclosing crystal. The term ophitic was originally applied to the structure of a Pyrenees rock, called ophite, in which the material of the enclosing crystal is augite and the enclosures are elongated crystals of a felspar.

For the development of this structure, the crystallisation of the two minerals must be *successive*.

d. In the *foliate* variety,† the arrangement of the constituents of the rock has a directional character; the mineral constituents of each kind being arranged in a series of streaks having a general parallelism of direction, though the surfaces of arrangement or the apparent layers are often more or less curved or irregular.

---

* *Pegma*, frame-work.

† *Folium*, leaf.

Another variety of holo-crystalline structure, the *orbicular*, though rare may be at this point mentioned. It is well manifested by a variety of diorite, often termed Napoleonite, which is found in Corsica. Owing to the difference in the colours of the two important constituents, the felspar being white and the hornblende dark green, the arrangement of the material of this rock in successive more or less spheroidal shells (in which the felspar or the hornblende is alternately predominant) round nuclei one or two or even more inches apart, is obvious to the eye, especially if the surface of the rock is polished. The constituents of each spheroid are elongated in form and directed towards the nucleus, thus yielding a radiate arrangement.

The name *granulitic* has been given to a variety of holo-crystalline structure presented by some of the dolerites: in a microscopic section of such a rock, rounded grains of pyroxene and olivine appear to be irregularly embedded among interwoven lath-shaped crystals of felspar.

3. *Varieties of mero-crystalline and vitreous structures.*

Flow-structure is a variety not only of mero-crystalline and vitreous, but also, as already mentioned, of fragmental structures, and is of great importance as generally (though not always) indicating that the rock was once either a mud or in a molten condition. The enclosures are arranged in stream-lines: in any section of the rock parallel to the stream-lines, the smaller enclosures are seen to have their longer diameters in the stream-lines, and to sweep round the larger enclosures as if their motion had been impeded by the latter. This structure sometimes presents a similarity to that of a stratified rock.

Flow-structure, however, may result from a very minute relative motion of the particles; for it may be induced, even in a solid material, by means of great pressure.

Spherulitic structure is a variety of vitreous and fine-grained mero-crystalline structures: it is characterised by the presence of spherules in the glassy or fine-grained material, each of the spherules being composed of fibrous crystals, which radiate from a centre and are of such a form that they must have originated in their present positions relatively to the matrix. The structure may be artificially produced in glass, by prolonged maintenance of the material at a temperature near its fusing point.

Names of kinds of structure.

Of the above kinds of structure, the more common are often briefly indicated by reference to those of certain kinds of rock, for instance, crystalline schist, granite, trachyte, obsidian: the structures of those kinds of rock being respectively termed *schistose*, *granitic*, *trachytic* and *vitreous*.

Various other names, such as *crypto-crystalline*,* *felsitic*, *micro-felsitic*, *crypto-felsitic*, have been given to structures or material of which the texture is so fine as to be beyond the range of optical analysis.

Cellularity; porosity; perlicity.

Cellularity, porosity, and perlicity are characters which depend on the presence of numerous cavities or cracks throughout the rock-fragment, and are thus very closely related to the composite character termed structure.

a. A rock is said to be *cellular* when it contains numerous round cavities: varieties of the cellularity are termed *vesicular*, *scoriaceous*, or *pumiceous*, according to the proportion which the volume of the cells bears to the whole volume of the rock-fragment containing them. When the rock is pumiceous, the volume of the cells is so large that the material floats, or almost so, when thrown into water; the material itself is in such case termed *pumice*.

---

* *Kruptos*, hidden.

In some rocks there are round cells, with a smooth internal surface, which are partially filled with simple minerals, often zeolites; in others, similar cavities, ranging from a fraction of an inch to a foot in diameter, are completely filled with such minerals. In these cases the rock is said to be *amygdaloidal,*[*] as the cavities, and therefore also the enclosures, sometimes resemble an almond in shape. As the minerals in the cavities are all such as may have been formed after the rock itself by water which has percolated through the mass, we may assume that the cavities were formed in the same way as those of lava; on the cooling of the rock, the condensation of the steam in each cavity would cause a suction towards the cavity through any minute fissures communicating therewith.

b. A rock is said to be *porous* when it contains a system of continuous cavities of irregular angular shape and of considerable volume. Such cavities do not owe their origin to the expansion of vapour in a viscous mass; they sometimes are a result of the removal of the more easily decomposed constituents of the already solidified rock by means of some disintegrating agent.

That rocks vary considerably, as regards the volume and continuity of the empty spaces which separate their constituents, is shown by the differences in the weights of water which can be absorbed by different kinds of rock having the same volume. The destructive action of rain and frost is closely related to the *absorptive capacity* of a rock, and the numerical expression of the absorptive capacity is thus of economic importance in the selection of a building-stone.

c. A *perlitic*[†] character is met with in some vitreous rocks: it is not a mode of arrangement of original constituents, but essentially consists in the presence of cracks having approximately spherical forms: in a section the curves are not closed. The cracks appear to have been caused by the stresses consequent on the cooling and contraction of the rock. Perlitic cracks have been artificially produced in Canada balsam.

---

[*] *Amugdale,* an almond.

[†] *Perlitic:* so named because conspicuous in rocks termed *perlite* or *pearlstone* by reason of their pearly lustre.

FISSILITY.

A rock-fragment is said to be *fissile* when it can be split along planes perpendicular to one or more directions. Fissility along a plane is due to the cohesion of the rock at points lying in the plane being least in the direction perpendicular thereto; the inferior cohesion of a rock along a certain direction may be due to one or other, or to a combination, of several varieties of structure.

One kind of fissility is termed *lamination*, another *cleavage*.

(a). *Lamination.*

On the one hand, fissility may belong only to parallel planes at an appreciable distance from each other: the fissility is then termed *lamination*. In rocks which have had a sedimentary origin, laminar fissility along particular planes parallel to the surface of deposit may have resulted in various ways; for instance, through an occasional temporary change in the nature of the sediment which was being deposited, or through occasional exposure of the surface to special influences before the deposit of the next superior layer began: without some such cause a sedimentary rock, although stratified, is not fissile in the direction of the layers.

(b). *Cleavage.*

On the other hand, if a rock-fragment is fissile in the same direction at every point in it, the fissility is termed *cleavage*; the character is very marked in clay-slates.

Experiment shows that cleavage may be induced in a plastic material, such as wax or clay, by the application of great pressure.

That the cleavage of clay-slate is a secondary character imparted to the rock subsequently to its formation is clear from the fact that, although the rock-mass is itself of sedimentary origin—as is established by its included fossil remains and the stratification—the direction of the cleavage is independent of that of the layers of deposit: cleavage is often subsequent in origin even to the contortions of the stratified beds, for it may retain constancy of direction throughout a mass in which there has been much crumpling of the layers. The distortion of the fossil remains is consistent with the view that the cleavage of clay-slate is due to a compression of the mass perpendicularly to the direction of the cleavage; and, in fact, the direction of the cleavage is always found to be parallel to the long folds which have resulted from the compression of the mass. Excellence of cleavage could only be expected to be developed in a fine-grained, fairly homogeneous and somewhat yielding material.

A gradual compression due to mere weight of superincumbent matter seems to be generally insufficient to produce cleavage, though it probably conduces to the development of laminar fissility.

(c). *Other kinds of fissility.*

And it is clear that any directional character which can be referred to a system of parallel planes may have for result a maximum or minimum cohesion of the rock perpendicular to those planes: in the latter case, the planes may be surfaces of fissility.

For example, the disposition of numerous crystals of mica or felspar in such a way that their directions of cleavage are parallel throughout a rock-mass would have for result a corresponding fissility, of which the degree of excellence and uniformity along a given plane would depend on the relative areas of the cleavable and uncleavable material and the degree of cohesion of the latter. Again, if some of the immediate constituents are arranged with their broadest dimensions in parallel planes, there may be a minimum of cohesion perpendicular to those planes, owing to the cohesion for a unit-area being less for those constituents than for the other material, or to the larger surfaces of union of those constituents with the matrix being surfaces for which the adhesion for a unit-area is a minimum.

Such kinds of fissility are presented by micaceous sandstones, crystalline schists and phonolites.

Hardness.

Hardness is a character of the immediate constituents themselves, and is only a noteworthy character of the assemblage when the rock is so fine in grain that the hardness of the individual constituents cannot be separately determined, or when the adhesion of the different individuals to each other is of appreciable importance as compared with the cohesion of the parts of an individual itself. The hardness of a fine-grained rock relative to that of a knife-blade is nevertheless sometimes useful for discriminatory purposes, as suggesting the possible presence or absence of particular minerals.

Fracture.

The *kinds of fracture* (even, splintery, etc.) of a rock depend on the kind of fracture of each of the constituents, on the sizes and arrangement of the constituents, on their modes of union, and on their cohesive and adhesive power: still, the character has little discriminatory value, for even in specimens of the same kind of simple mineral there is much difference in the mode of fracture.

Elasticity.

In some cases the material of a rock is so *elastic* that a fragment gives a clinking sound when struck with a hammer; one kind of rock, phonolite,* owes its name to the manifestation of the character.

Flexibility.

Some rocks, when in the form of a slab, are so *flexible* that the slab, if held at the two ends, bends perceptibly under its own weight; flexibility is a very prominent feature of some sandstones met with in Brazil and India.

---

* *Phone*, a sound.

Degree of coherence.

According to the degree of coherence of the constituents, the rock may be *compact, friable, crumbly,* or *loose:* if the coherence is small and the constituents are minute, the rock is said to be *earthy.*

Compact rocks, even when belonging to the same kind, differ very much in their power of resistance to a crushing force (*frangibility*), and the architect has to pay special attention to the character in his selection of building material. A one-inch cube of granite will in some cases withstand a pressure of 13,000 lbs.

Order of formation of the immediate constituents.

The *order of formation* of the various constituents of a rock-fragment can often be inferred if attention is directed to the forms of the constituents; the completeness of the crystalline development of the constituents belonging to one kind, and the incompleteness of the development of the constituents belonging to another, are frequently to be accounted for by the former constituents having separated from a cooling molten mass before the latter. Further, the forms and arrangement of the various constituents may indicate that certain of them have been formed at a comparatively late stage in the history of the mass by alteration of some of the constituents of prior formation. All characters which render it possible to make satisfactory inferences relative to the history of the rock-mass are of special importance.

Relative proportions of the immediate constituents of different kinds.

The average relative proportions of the different kinds of immediate constituents of a rock-fragment form an important character of the assemblage, though they can rarely be directly or indirectly determined with any high degree of precision.

Percentage chemical composition.

The *percentage chemical composition* of a rock-fragment is directly dependent upon the chemical composition and relative proportions of the various kinds of immediate constituents: it is generally impracticable to isolate each kind of individual constituent for separate analysis or for determination of the proportion of the constituents of each kind, and the average chemical composition of the rock is thus of service as suggestive of the kinds of mineral possibly present and of the proportions which they bear to each other; or again, it may indicate the chemical composition of the molten material from which, by consolidation, the rock may have been produced.

Specific gravity.

In the same way, the *specific gravity* of a rock-fragment is directly dependent on the specific gravity and relative proportion of each kind of immediate constituent: where a complete mineralogical and chemical analysis is impracticable, the specific gravity of a rock is useful as suggestive either of the specific gravities of those consuituents of which the nature is uncertain, or of the proportions of the different kinds of known constituents to each other.

Colour.

The *colour* of a rock is the resultant effect of the colours of the immediate constituents, and depends on the colour of each kind of constituent and on the sizes and arrangement of the individuals. It is even of less value than in the consideration of simple minerals, but is occasionally useful as suggesting the possible presence or absence of certain kinds of minerals of which the colour is not ordinarily subject to great variations.

B. Petrical characters

(i.e., characters belonging only to large parts of the rock-mass or to the rock-mass itself).

The more important characters of large parts of the rock-mass or of the rock-mass itself are the following:—

1. The mutual relations of the parts of the rock-mass.
2. The presence of joint-planes or divisional planes.
3. The shape of the bounding surface.

1. *The mutual relations of the parts of the mass.*

It has already been pointed out that the parts of a rock are similar, not identical, in their characters, and that adjacent masses showing considerable differences of characters may sometimes be intimately related to each other: further, mention has been made of some of the ways in which such differences of characters, whether confined to a minute portion or extending through a large portion, might be originated. A complete knowledge of a mass necessitates a determination of the lithical characters of all parts of it: though a complete determination is impossible, the examination of a number of fragments obtained from different and well-distributed parts of the mass may render possible a correct inference as to the lithical characters of the remainder. And it is further necessary, not only to determine the lithical characters of the parts but to ascertain whether or not the characters are continuous from one part to another; a determination more readily made where the rock shows a directional character—for instance, stratification or cleavage—than where such directionality is absent.

The direction of a particular plane of a rock-mass may be conveniently specified by a statement (i) of the direction (*strike*) of a horizontal line in the plane, (ii) of the acute angle (*dip*) which the plane makes with the horizontal plane containing the line of strike, and (iii) of the point of the compass to which a line, at once horizontal and perpendicular to the line of strike, is directed; that end being used as index which is nearest to the lower part of the particular plane.

An arrangement of characters relative to a system of surfaces, of which the members of each consecutive pair are everywhere at the same distance from each other, is not necessarily of undoubted sedimentary origin: it is shown by crystalline schists of which the mode of origin is often not sedimentary, and even by masses which are known to have flowed as lava. For example, successive flows of very fluid lavas over a nearly horizontal surface would furnish a composite mass of which the characters might be similar throughout any one plane of a parallel system, but different in different planes of the system.

As already mentioned, the flow-structure of a rock which has once been a viscous lava sometimes resembles the stratification of a sedimentary rock.

Discontinuity of characters is of various kinds and due to very different causes which may have been antecedent to, contemporaneous with, or subsequent to the epoch of formation of the rock: for example, local difference of chemical composition, introduction and enclosure of foreign matter, simple fracture, fracture combined with a relative motion of one part along the fissure (*faulting*), fracture combined with a mixing of fragments from different localities; and so on.

Constancy of character or continuity of change of character may be due either to the constancy or continuity of change of the circumstances of formation or alteration of the rock, or to an effacement of discontinuity.

Those parts of a mass which are most exposed to the action of air and water show generally a continuous change of character, the amount of the change being less as the distance from the exposed surface increases: such parts are said to be "weathered."

The weathering action sometimes reveals to the eye peculiarities of structure which might otherwise escape attention: for by the removal of the more easily decomposed constituents others of a less easily altered kind are rendered conspicuous.

A continuous change of character, varying in intensity with the distance from the junction of two masses, suggests a relationship of the surface of junction to the origin of the change: the mass may have acquired the differences of character *before* the epoch of formation of the adjacent mass, and the changes have been due to weathering or to differences of circumstances of cooling from a state of fusion: or the differences may have been acquired *contemporaneously* with the formation of the adjacent mass, which may, for example, have been in a hot fluid condition when it assumed its position: or again, they may be of origin still *later* than the time of formation of the adjacent mass, and have been caused by percolating fluids which have obtained access along the surface of junction.

The most important variations of character due to the presence of foreign material are those which indicate the inclusion of organised matter at various times during the formation of the rock: from the mineralogical point of view, they are important as showing that the circumstances of formation of the rock were of a kind which did not involve the immediate destruction of organised material. Further, the distribution through a rock-mass of animals or plants which can be inferred from their structure to have habitually lived in water, either saline or fresh, or on dry-land, may lead to a knowledge of the mode of formation of the rock.

Though most of such rocks can in this way be demonstrated to have been produced by the deposition of fine material from a state of suspension in water, it may be remarked that evidence of the inclusion of organised matter is compatible with a volcanic origin of the rock. At Pompeii and Herculaneum have been found skeletons of inhabitants who had been suffocated there by volcanic dust or mud nearly 1800 years before, and at Hawaii a stump of a tree, only superficially charred, has been seen to be still standing in the midst of a cooled lava-stream.

2. *Joint-planes or divisional planes of the rock-mass.*

A large rock-mass, as met with in Nature, is not continuous in material, but is generally divided, by one or more sets of parallel cracks, into smaller masses having plane faces: these faces are termed *joint-* or *divisional* or *structural planes.* The latter term is used by those authors who reserve the term structure for use in the description of the characters of large masses: the term is not very appropriate, however, for the large mass was not constructed by the separate juxtaposition of these smaller masses, as the term might lead one to suppose.

If the joint-planes have only one direction, the mass is naturally divided into tabular blocks of indefinite size.

If they have two or more directions parallel to one line, the mass is divided into columns, sometimes with five or six sides; generally the columns are separated into shorter ones, of which the joints are usually curved, sometimes simulating a ball-and-socket or even a mortice-and-tenon arrangement.

If the joint-planes have three directions, not all parallel to a single line, the mass is naturally separated into parallelepipedal blocks, which may conceivably be cubes if all the angles of the blocks are right angles.

Joint-planes are distinct from planes of fissility in that they are planes of actual discontinuity of material: the blocks themselves show no fissility parallel to their joint-planes.

Joint-planes are often due to the shrinkage which resulted on the cooling or drying of the original continuous masses, or to strains consequent on a distortion of the mass by an earth-movement: sometimes, they may result from the removal of thin bands of more readily decomposed matter.

They are of obvious advantage to the quarryman in that they make the extraction of large blocks more practicable: they are important in the history of the rock as bringing large surfaces in the interior of the mass within the reach of disintegrating agents.

3. *The shape of the bounding surface of the rock-mass.*

The shape of a rock-mass can never be more than roughly determined; and it is always more or less accidental, since it depends on the shape of the surface upon which the rock has been deposited and on the kind and amount of alteration to which the rock has since been subjected.

Sometimes the shape is of importance as suggesting a mode of origin of the mass: in this respect, the following varieties of shape may be specially mentioned: —

a. Part of the boundary consists of two plane or curved surfaces equidistant from each other throughout their extent.

1. Such a mass may have been deposited upon an approximately horizontal surface, either (*a*) as a sediment or (*b*) after flow in a liquid or viscous condition: or again,

2. while still a mud or in a viscous condition, it may have flowed down into a fissure, or have been forced between two other masses or two parts of the same mass, initially in contact with each other.

In the former case the rock could send off-shoots only along cracks in the rocks beneath it; but in the latter case it may send off-shoots into the rocks on both sides of it, and parts of the same continuous mass may appear between different pairs of rocks, owing to the intruded material having broken through a weak place in the intervening mass.

3. Or again, sediment may have filled up a fissure.

Further, in the case of a sediment, there will be comparatively little alteration of the rocks on which it is deposited and the change will be due generally to the action of water: the surfaces of rocks with which a molten mass comes into contact may, however, be more or less baked, and thus only the lower or both the upper and lower masses may be altered near the junction, according as the molten mass took up its position before or after the upper rock was formed. An alteration of the lower rock is not necessarily due to the matter now superincumbent, but may have been due to weathering before the upper one came into existence.

If curved, the mass may have been crumpled and contorted since its formation.

A rock-mass which is somewhat like a wall in shape and position, and is inferred to have filled a more or less vertical fissure in the earth's crust, is termed a *dyke;* a mass which is inferred to have once been an intrusive sheet of molten matter is termed a *sill.*

β. *Lenticular shapes.*

In some cases the lenticular shape has resulted when a molten mass, probably very viscous, has been intruded between two rocks having a plane junction, and has accumulated largely round the vent, owing to the difficulty of either breaking through the upper mass, or of forcing its way far along the junction before it has cooled so much that its mobility has ceased; such a mass has been termed a *laccolite.* Or again, the mass may have been transformed from some other shape to the lenticular as a result of enormous unequally distributed pressure.

γ. *Elongated shapes.*

An elongated stream-shaped mass may have once been the bed of a river, or, on the other hand, have flowed as lava from a volcanic vent. A mass which is in part rudely cylindrical may have consolidated as lava in the neck of a volcano.

δ. *Irregular boss.*

An irregular boss may once have been in a molten state, in which case off-shoots or veins may diverge from it into the adjacent rocks.

The distribution of rocks into kinds.

Classification of natural products.

Natural products may be said to be of the same kind, and may be designated by the same name, if they have a single character or a group of characters in common. There are thus different sorts of kinds, according to the number and importance of the characters which the products belonging to the same kind have in common. It is possible to recognise a gradation of similarity of character, and to distribute all the products into sorts of kinds such that each sort is included in a more general one; the different grades being distinguished by special terms. Thus for animals and plants, different grades of similarity have been designated by the terms, *species, genus, order, family* and *class;* a set of individuals having certain characters in common constitute a *species*, a set of the species having certain characters in common constitute a *genus*, a set of genera an *order*, a set of orders a *family*, a set of families a *class*, and all the classes the *Kingdom.*

Object of the distribution into kinds.

As natural products are only distributed into kinds so that general statements may be made about the products belonging to each of them, a particular distribution is useless if the common character or group of characters employed for the distribution is such that any further general statement relative to the products of that kind is impossible. For example, the distribution of rocks into kinds by means of colour, or density, or hardness, or shape, or joint-planes would be futile: no general statement, true only of white rocks, can be made, except that they are white, for in their other characters white rocks differ from each other quite as much as they differ from those of another colour. By reason of the variations of character in what must be regarded as a single body, the liability to alteration during lapse of time, the absence of a distinctive shape of boundary, and the general want of individuality, the distribution of rocks into kinds, and thus also the assignation of names, present great difficulties.

As far as possible, the kinds of rocks should be defined by means of characters determinable from small fragments, and both the kinds and names be independent of hypotheses.

Two rock-masses would obviously be of the same kind if all their characters were the same for both: but so high a grade of similarity is useless, and it is necessary to select some characters upon which special stress may with advantage be laid. Since a solid mineral product of considerable extent retaining much the same characters throughout is said to be a single rock-mass, the most convenient grade of similarity for use as a basis of nomenclature will be one which depends only on the similarity of some or all of those lithical characters of which the constancy throughout a mass is necessary to its simplicity. In such case, the name of the kind of a rock will depend only on the characters of parts of the rock-mass, and the characters of a fragment may suffice for the recognition of the particular kind of rock to which the mass itself is said to belong.

It is upon particular lithical characters, too, combined with their constancy throughout a considerable volume, that the economic value of a rock largely depends, and upon these characters the name of the material yielded by a quarry may conveniently be based: material presenting important differences of lithical characters, even if it belongs to the same mass will not have the same uses, and may, in many cases at least, be satisfactorily indicated by a completely different name.

And it is further desirable that as far as possible the distribution into kinds, and the nomenclature of rocks, should be based upon those lithical characters which can be determined from examination of fragments so small that a collection of the fragments can be easily carried for a long distance: occasion often requires that rocks shall be named, provisionally at least, by means of mere chips brought from a far-off country by a traveller for whom the transport of large fragments has been impracticable, and who has had himself no opportunity, perhaps not the requisite special knowledge, for the determination of the petrical characters of the respective masses.

It must be remembered, however, that from the scientific point of view, *the knowledge of a fragment is merely an aid to the knowledge of the whole;* and that the latter necessitates a determination, not only of the lithical characters of a fragment, but also of the degree and kind of variation of the lithical characters throughout the whole mass. As already pointed out, the whole of a rock-mass is not accessible to observation, and the lithical characters of all the parts can thus only be *inferred* from those observed in fragments broken from the mass here and there, in quarries, borings, mines and cliffs.

A single mass may consist of more than one kind of rock.

It follows from the signification of the term rock that different parts of a single mass are to be regarded as belonging to different kinds of rocks, if the parts are considerable in extent, and their lithical characters, though much the same throughout each part, show important differences in the case of the different parts.

It would doubtless have been an advantage if the relationships of such kinds could always have been indicated in their names. In particular cases, indeed, this is possible; for instance, one part having certain lithical characters may be termed basalt, while another part of the same mass, showing very different characters, may be termed basalt-glass. But such a mode of nomenclature would only be generally practicable, if a particular kind of rock, when merely part of a single body, had always the same kind of relationships, which is not necessarily the case: it is conceivable, for example, that a rock, though it may have lithical characters identical with those of basalt-glass, and ought thus to be denoted by that name, may be part of a mass of which every portion exhibits lithical characters different from those of basalt, and might thus, by virtue of its new relationship and on the same grounds as before, receive a different name. In fact, owing to denudation or other cause, the relationships of masses are often difficult or impossible to trace: only a single part of the original body may remain for investigation, or the former continuity of several now isolated masses having different lithical characters may be impossible to establish.

Since the parts of a rock-mass are only similar, not identical, in their lithical characters, a single rock-mass, and therefore a single kind of rock, must be allowed some amount of variation of lithical characters: the practical difficulty is to decide on the kind and amount of difference of characters to be allowed to rocks which we may wish to regard as belonging to the same kind. The limits of variation should be so chosen that it is as rarely as possible necessary to regard a single body as composed of different kinds of rocks.

Varieties of the same kind of rock.

Different masses or different portions of the same mass, considerable in extent, may present differences of character, which are neither negligible, nor yet sufficiently important to render it desirable to regard the rocks as belonging to different kinds; such rocks are conveniently termed *varieties* of the same kind, and are often designated by names which serve as a reminder of the relationship.

Rocks may be regarded as constituting a variety of a particular kind, owing to differences of one or several of those lithical characters which have been employed in the definition of that kind, or owing to the possession of one or more additional characters. For example, all rocks of which particular lithical characters approximate to certain values are said to belong to the kind called *granite:* those which only deviate to a small extent from a certain set of values are sometimes termed *common granite.* Another variety, termed *tourmaline-granite,* is constituted by rocks which in their lithical characters show the requisite approximation to the standard values, but at the same time present an additional character, namely, the presence of tourmaline as a mineral constituent : *graphic granite* is a variety in which the additional character is structural : *haplite*,* on the other hand, is a variety in the case of which one of the mineral constituents (mica) present in other varieties of granite is wholly, or almost wholly, absent.

Age is, in itself, an unimportant characteristic of a rock.

But if rocks are to be distributed into kinds by means of lithical characters, or indeed of any characters which can be actually observed, the age of a rock cannot be taken into direct consideration. And even in the case of animals and plants, age is in general of importance, not by reason of the mere lapse of time itself, but because the general changes of character of an individual are almost independent of external circumstances and are intimately related to the age; while further, the duration of the life of an individual is extremely limited.

Rocks of the same age and initially the same characters may eventually become quite different from each other.

But in the case of minerals and rocks the changes are not so closely related to the lapse of time; on the contrary, they largely depend on the nature and relative effects of the more or less local agents to which the rock happens to have been exposed, and are chiefly due to the mechanical action of wind and rain, stream and sea, to the chemical action of air, cold and hot springs, acid vapours, molten lavas, and to the mechanical and chemical actions resulting from enormous pressures. Two masses formed at the same time and identical in their characters may conceivably, owing to mere position in the earth's crust, be subjected to different kinds of agents of alteration, and thus become at a later time quite unlike each other in their general features.

* *Haploos*, simple.

The same mass may at one age belong to one kind, at another age to a different kind of rock.

If during lapse of time a large part of a mass, consisting originally of a single kind of rock, has undergone a similar change of character throughout, that part must be regarded as having become either a distinct kind of rock or a distinct variety of the original kind, according as the change of character is deemed to be with or without specific importance.

It would be in some respects convenient if the same mass could be regarded as always belonging to one kind, and could retain in its varietal names, through successive ages and changes, a token of its continuity of existence; and it would similarly be convenient if masses, originally identical in their characters but now in different stages of alteration, could be regarded as varieties belonging to one kind, and be distinguished by names expressive of the common relationship.

But there are grave practical objections to such a mode of distribution and nomenclature. The present characters of a mass can be actually determined; but a knowledge of the antecedent characters and thus of the original mass is only inferential, and is based on these determinations; though the latter were right, it would often happen either that the inference was wrong, or that more than one inference might be consistent with the observed characters: in any case, a name is more likely to be permanent and generally accepted if based directly on the present characters, than it would be if based merely on the antecedent characters inferred from them. Either failure to command general acceptance or likelihood of future change is fatal to the utility both of schemes of distribution into kinds and of nomenclature.

Though at first sight it would appear that great confusion must inevitably arise, if the kind to which a rock-mass belongs is not to be regarded as always the same and distinguished by the same name, yet it will be seen on reflection that similarly complete differences of name are found convenient, even in common life, for the designation of the different stages of existence of an individual belonging to the Vegetable or

Animal Kingdoms, as in the case of seed, shrub, tree; infant, child, youth, man; egg, caterpillar, chrysalis, butterfly.

Serpentine-rock, for example, is always a result of alteration of a preceding rock-mass; yet it is so definite in its characters that the kind is most satisfactorily distinguished by a special name: further, it has resulted from the alteration of rocks of more than one kind.

The age of a rock as indicating a particular time in the earth's history.

The age of a rock may also be had regard to from another point of view. A statement of the present age of a rock gives the time, measured on the scale furnished by the succession of the sedimentary rocks, at which the rock was formed; indeed, it is only by reference to the said scale that the present age of a rock can be actually determined and indicated. The present age of a rock thus corresponds to the age of the earth itself at the time of the formation of the rock; now the nature of a rock at the time of its formation, and thus also its present characters, depend on the *condition of the earth* when the rock was formed, and thus on the age of the earth itself at that time, or, what comes to the same thing, on the present age of the rock. In some schemes of classification, the kind to which a rock-mass is to be assigned and the name of the kind are, for this reason, made to depend on the epoch during which the rock-mass was formed: rock-masses indistinguishable from each other in their present characters being assigned to different kinds and receiving different names according as they were formed before or after the beginning of the Tertiary Epoch. But if the principles enunciated above be accepted, regard should be had, in the distribution of rocks into kinds, only to their present characters: rock-masses, whether formed at the same or different times in the earth's history, should only be assigned to different kinds if their present characters are essentially different from those of each other.

Selection of characters to be used for the distribution of rocks into kinds.

Having determined, then, that rocks should be distributed into kinds by means of lithical characters alone, it remains to discover upon which lithical characters stress is to be laid. In the first place, those subordinate characters, such as colour, which result from the principal characters, however convenient they may be for the purposes of mere *recognition*, may here be left entirely out of consideration; for being themselves dependent upon, and indeed necessary consequences of the principal characters, they are superfluous for the purpose of *distribution into kinds.*

In the next place, importance can only be attached to those principal characters which are found to be generally persistent throughout large portions of a single mass; otherwise, either rocks as thus defined—*i.e.* large mineral masses presenting a general similarity of characters throughout—would have no real existence, or at any rate every single mass would consist of many different kinds of rock. Thus the only characters upon which stress can be laid are :—the specific simplicity or compositeness of the immediate constituents : and the species (including the chemical composition), the crystallised or amorphous condition, the complete or fragmental state, the relative proportions, and the arrangement of the various constituents.

These characters can be most conveniently considered in two groups, as :—

1. *Mineral composition, and the relative proportions of the various mineral constituents ;*
2. *Structure :*

the latter being, as already explained, not a simple character but a natural association of several important simple characters.

The distribution of rocks into sharply defined kinds is impracticable.

In the case of simple minerals, the chemical composition and the crystalline form or cleavage are characters capable of precise determination and numerical expression, and further lead to the distribution of minerals into kinds which are sharply separate from each other: but, in the case of rocks, the mineral composition and the structure of a fragment are not determinable with such precision; and moreover, though they are the most constant of the characters, are yet sufficiently variable throughout a single mass to render a sharp definition of kinds by means of them impracticable.

Mineral constituents of a single rock-mass.

Principal and subordinate; normal and abnormal.

As regards the mineral constituents of a single rock-mass, those which are present in large proportion may be termed *principal* constituents of the *mass* or of *part of the mass;* others, which are in small proportion and may either be well distributed through the mass or be local or irregular in occurrence, may be termed *subordinate.*

The constituents which are well distributed, whether principal or subordinate, may be termed *normal* constituents of the *parts of the mass;* those subordinate constituents which are local or irregular, *abnormal.*

Mineral constituents of rocks belonging to a single kind.

Essential and accessory.

The mineral constituents which must be present in all rock-masses which are to be regarded as belonging to one kind are termed *essential* constituents for the *kind:* others which, though unessential, are present in a particular rock-mass belonging to the kind, are termed accessory: both the essential and accessory constituents may be either principal or subordinate constituents of a particular fragment.

A special development of either an essential or an accessory constituent, if manifested throughout a large volume, may be sufficiently important to render its recognition as the mark of a variety desirable. For example, granite may be defined to include all rocks which have a crystalline-granular or pegmatic structure without directional character, and have a potash-felspar and quartz as constituents: those constituents are thus said to be essential to the kind; any fragment of a rock-mass belonging to the kind, if large enough to show the average lithical characters of the mass, contains a potash-felspar and quartz as mineral constituents. In a granite-mass, as thus defined, accessory species are however generally present, either as principal or subordinate constituents: in most masses mica is present, and is thus a normal constituent; it is generally a principal constituent, so much so that its absence or its presence in small proportion, combined with the absence of other principal constituents than a potash-felspar and quartz, has been made the mark of a variety (haplite): hornblende or tourmaline is also sometimes present as an accessory principal constituent.

Consideration of different kinds of rocks.

With the above in mind, it is desirable now to consider different kinds of rocks, whether sharply defined or not; and further, to ascertain what relationships between the kinds are suggested by the differences and resemblances of their lithical characters.

With this end in view, it will be instructive to first give attention to various kinds of rocks which received distinctive names from the earlier mineralogists: for it may be taken for granted not only that those kinds which are most common and distinct from each other would first attract notice, but that differences of kind would initially be based on those differences of character which are obvious on mere inspection of specimens, or are determinable by the simplest modes of experiment.

It thus becomes desirable to first concentrate attention on the salient characters and relationships of the kinds of rocks to which the names in the following alphabetical list have been given:—

Andesite.
Basalt.
Breccia.
Chalk.
Clay.
Coal.
Conglomerate.
Crystalline schist.
Diorite.
Dolerite.
Dolomite-rock.
Euphotide.
Felstone.
Gneiss.
Granite.
Hæmatite-rock.
Lava.
Limestone.
Marble.
Obsidian.
Phonolite.
Quartz-rock.
Rhyolite.
Rock-salt.
Sandstone.
Serpentine-rock.
Shale.
Slate.
Syenite.
Trachyte.

As the above kinds of rocks, selected from hundreds which have now received distinctive names, must be considered in some definite order, a preliminary grouping will be adopted which is *immediately* suggested by the differences of mineral composition or structure: it may afterwards be possible to devise other orders and groupings, which will bring nearer together kinds of rocks similar in other and still more important characters, or which will separate more widely rocks different in characters having much significance though appealing less directly to the unaided eye.

Preliminary grouping of the above kinds of rocks.

A preliminary, though more or less overlapping, arrangement of the above-mentioned rocks into groups, by means of such lithical characters as are determinable without microscopic examination of thin sections, is the following:—

I. Rocks presenting a directional variety of structure.

Crystalline schist, gneiss, slate, shale.

II. Rocks essentially composed of material belonging to a single mineral species.

Rock-salt, hæmatite-rock, quartz-rock, calcite-rock (chalk, limestone, and marble), dolomite-rock, serpentine-rock.

III. Rocks which, though really composed of material not belonging to a single definite mineral species, are so far homogeneous in aspect that the essentiality of the compositeness is concealed from the unaided eye.

Coal, clay, obsidian, phonolite, felstone.

IV. Rocks which are similar in the above character to those of the last group, except that they contain simple minerals porphyritically dispersed through them.

Rhyolite, trachyte, andesite, basalt.

V. Rocks which are composite in kind of material, holo-crystalline, and without directional lithical characters.

Granite, syenite, diorite, dolerite, euphotide.

VI. Rocks having aggregate structure.

Breccia, conglomerate, sandstone.

VII. Cellular rock.

Lava.

It is necessary, at this point, to indicate briefly the distinctive characters of each of the above kinds of rocks.

I. Rocks presenting a directional variety of structure.

CRYSTALLINE SCHIST, GNEISS, SLATE, SHALE.

The directional varieties of structure are so evident on mere inspection of specimens and of so frequent occurrence in Nature that they immediately suggest themselves, whatever their origin, as marks to be used for the distinction of particular kinds of rocks; hence, whatever their mineral composition, the rocks showing the foliate variety of holo-crystalline structure are regarded as of one family, and have been termed *crystalline schist* or *gneiss*, according as felspar is absent or present as an essential constituent. Those rocks which are cleavable have been termed *slate:* others, which show laminar fissility, *shales*.

If a mass of crystalline schist is of essentially simple mineral composition, the kind may be indicated by means of a composite name; thus a rock having a foliate holo-crystalline structure and consisting essentially of talc is termed talc-schist. The same method of nomenclature is practicable even in the case of a composite crystalline schist, if only one of the essential species be selected as an indicator and be regarded in the name; for instance, mica-schist is the name given to a crystalline schist of which mica is not the only essential constituent; a second mineral, quartz, is not only an essential constituent, but may be even more abundant than the mica itself.

Slates and shales, being generally of very fine texture, may appear of simple mineral composition to the unaided eye, and then be placed also in the third of the above groups.

II. Rocks essentially composed of material belonging to a single mineral species.

ROCK-SALT, HÆMATITE-ROCK, QUARTZ-ROCK, CALCITE-ROCK, DOLOMITE-ROCK, SERPENTINE-ROCK.

Each of these rocks, whether showing a directional variety of structure or not, attracts special attention as being composed essentially of material belonging to a single mineral species.

All the rocks which are essentially composed of material belonging to the same single species of mineral may be regarded as belonging to a distinct kind, and in such case the name of the mineral may be used in the denomination of the rock-kind, as for instance quartz-rock: convenience, however, rarely requires the assignation of a distinctive name to such a kind.

But where rock-masses, though composed of material belonging to one and the same species of mineral, show important differences of structure or other physical characters, it is sometimes found convenient to denote each variety by a name consisting of a single and completely different word. Masses of what might be termed calcite-rock, for example, differ so much in physical characters that several kinds have their own particular uses and are denoted most conveniently by short special names: one of them, chalk, is white and soft, and unsuited to the requirements of the architect; another, limestone, is more variable in colour, harder, but yet very easily worked, and is much used as a building-stone; a third, marble, is still more compact, takes a good polish, and if of pleasing colour or arrangement of colours is used for decorative purposes.

III. Rocks which, though really composed of material not belonging to a single definite mineral species, are so far homogeneous in aspect that the essentiality of the compositeness is concealed from the unaided eye.

COAL, CLAY, OBSIDIAN, PHONOLITE, FELSTONE.

Certain other rocks, though at one time regarded as each consisting essentially of a simple mineral and designated as such by a special name, have since been found to be of a composite nature. Even before the application of the microscope to the examination of thin rock-sections, the merely apparent nature of the simplicity of these rocks was inferred, owing to the impossibility of expressing the chemical composition by a formula of simple type, or to the differential action of an acid on the material, or to the gradual transition in the mass from an apparently simple to a distinctly heterogeneous material having the same average percentage chemical composition.

Of such only apparently simple rocks, soon distinguished by special names, may be mentioned:—

Coal, clay, obsidian, phonolite, felstone.

Coal is distinguished from all other natural products by its colour, brittleness, and combustibility. Its physical characters in general and its chemical composition are very variable: it is thus not a definite mineral species.

Clay is distinguished by its dull aspect and earthy character when dry, and by its plasticity when mixed with water. There are clays of various kinds, all consisting in great proportion of alumina, silica, and chemically combined water (with some oxide of iron and alkalies), but most of them very impure: when the impurity is relatively large and consists of fine sand and hydrated oxide of iron, the material is called *loam:* if the impurity consists largely of carbonate of lime, the material is called *marl.*

Obsidian, *phonolite* and *felstone* are so far homogeneous in aspect that they were regarded, during the early part of the century, as truly simple minerals; the common porphyritic enclosures being treated as unessential constituents. By reason of their degree of hardness and their chemical composition (silica, alumina, alkalies, and sometimes lime), they were classified as being allied to the felspars.

Obsidian was distinguished from the allied minerals by its vitreous lustre and conchoidal fracture: phonolite or "slaty felspar," and felstone or "compact felspar," by their stony aspect and compact texture; phonolite being further remarkable for its fissility and the large percentage of soda in its composition. It was eventually found, however, that notwithstanding their similarity to the felspars the above substances are each incapable of reference to a definite type of chemical formula, and are thus presumably only mixtures of definite chemical compounds in indefinite proportions.

Phonolite, though simple to the naked eye, was found to be chemically heterogeneous, for on treatment of the powdered rock with hydrochloric acid, one portion readily dissolves while the other is comparatively unacted upon: in chemical composition the former part corresponds approximately to nepheline, the latter to a felspar (orthoclase).

Though felstone has been long regarded as essentially composite, the nature of the heterogeneity is less easily established, for its minute constituents cannot, like those of phonolite, be separated from each other by means of solvents: on various grounds, hardness, fusibility and chemical composition, it was thought by the earlier mineralogists to be, in great part at least, an intimate admixture of felspar and quartz: this interpretation receives support from the results of the optical examination of thin sections.

IV. *Rocks which are similar in the above character to those of the last group, except that they contain simple minerals porphyritically dispersed through them.*

RHYOLITE, TRACHYTE, ANDESITE, BASALT.

Other kinds of rocks, termed *basalt* and *trachyte* * respectively, were distinguished by the fineness of their texture and the frequent presence of definite minerals as porphyritic enclosures in the very fine-grained ground-mass. Notwithstanding the apparent simplicity of the ground-mass, its probably composite nature was soon asserted by mineralogists: the ground-mass of basalt, generally very dark in colour, was inferred, chiefly from its chemical composition, to consist largely of augite; that of trachyte, generally very light in colour, was on similar grounds inferred to consist in great part of felspar: further, augite, hornblende and olivine were distinctly recognised as normal enclosures in basalt; "vitreous felspar" and mica as normal enclosures, and quartz as an occasional or abnormal enclosure, in trachyte.

As the collection and chemical analysis of rock-specimens advanced, it was inferred that, in addition to augite, there is more or less felspar in the ground-mass of basalt, and that in rock-masses presenting the general characters of basalt and trachyte, the proportion of felspar and augite in the ground-mass varies indefinitely between two extremes. The rocks near the extremes being designated basalt and trachyte respectively, the name *andesite* † came to be given to intermediate rocks, which could not be more satisfactorily assigned to one extreme than to the other.

---

* *Trachus*, rough: because of the aspect of a surface of fracture.

† So termed, because common in the Andes.

As already stated, the rocks first distinguished as trachyte were rarely found to contain quartz as a porphyritic enclosure: but when the rocks of Hungary were closely examined, it was discovered that in that country rocks which would on general grounds be designated trachyte were remarkable as often containing enclosures of quartz (*quartz-trachytes*), and as generally containing a higher percentage of silica whether present as quartz or not, than the trachytes of other localities. To such rocks the name of *rhyolite* * has been given.

The percentage of silica in felspar being generally greater than that in augite, there is also a tendency to a gradual decrease in the percentage of silica as we pass from trachytes to andesites, and from andesites to basalts: but as the percentage of silica varies from 43 to 69 in different kinds of felspar, and from 42 to 56 in different kinds of augite, the percentage of silica in the above rocks depends largely on the kinds of felspar and augite as well as on their relative proportions.

Similarly, as the specific gravity of quartz (2·65) and felspar (2·6—2·7) is less than that of augite, hornblende and olivine (3·2—3·4), there is a gradual increase of the specific gravity in the passage from rhyolites to basalts.

And further, as quartz and felspar are generally much lighter in colour than the ferriferous minerals augite, hornblende and olivine, there is usually a darkening of colour during the passage from rhyolites to basalts; so much is this the case that it was at one time proposed to call the intermediate rocks *greystones*. The colour of a rock, however, depends on so many unessential circumstances, that it is impracticable to lay much stress upon it as a discriminative character.

---

* *Rhuas,* fluid: because of the frequent flow-structure.

V. Rocks which are composite in kind of material, holo-crystalline, and without directional lithical characters.

GRANITE, SYENITE, DIORITE, DOLERITE, EUPHOTIDE.

The rocks of another group attract attention by the fact that they consist, in each case, wholly of distinctly crystallised constituents, belonging to two or more species, separate from each other and mutually interpenetrant: further, the structure is without directional character.

In these rocks, the association and the relative proportion of the mineral constituents are regarded as sufficiently important to be made use of in the differentiation into kinds, each kind being distinguished by a special name. Important members of the group were soon distinguished as granite, syenite, diorite, dolerite and euphotide: *granite* as consisting of felspar and quartz (and normally mica); *syenite** and *diorite*,† of felspar and hornblende, felspar being predominant in the former, hornblende in the latter; *dolerite*,‡ of felspar and augite, "the crystals being interlaced"; *euphotide* § (Haüy), of "compact tenacious felspar" (*i.e.*, altered felspar) and diallage. In the course of time it was remarked that the felspar of syenite is different from that of diorite not only, as above remarked, in its proportion to the hornblende, but also in its physical characters and chemical composition: the former (orthoclase), like that of most granites, is a potash-felspar with rectangular cleavages; the latter (with that of dolerite) is a lime-soda felspar, with cleavages inclined to each other at an angle slightly different from a right angle.

---

* The ancient *Syene* is the modern Assouan, Egypt: the Assouan rock is now termed hornblende-granite.

† *Diorizo*, to distinguish: the colours of the two constituents being distinct.

‡ *Doleros*, deceptive: because similar in appearance to some kinds of diorite.

§ *Eu*, well, *Phos*, light: because of the lustre.

VI. Rocks having aggregate structure.

BRECCIA, CONGLOMERATE, SANDSTONE.

Rocks of another group, whatever their true origin, bear a striking resemblance in their structure to coarsely fragmental matter aggregated together. The constituents, whether apparently or really fragmentary, are themselves either simple or composite in kind of material; they have their edges either sharp or more or less rounded; they are not mutually interpenetrant; their intervening spaces are usually filled with cementing matter. When the constituents of such a rock are small, they sometimes resemble sand-grains and consist largely of quartz: the rock is then called a *sandstone*, whatever the cementing matter. If the constituents are larger than ordinary sand-grains, the rock is called a *breccia* or *conglomerate*, according as the edges of the constituents are sharp or rounded: the constituents are generally less simple in material and less similar to each other than those of a sandstone.

VII. Cellular rock.

LAVA.

Lava generally shows a strong likeness to furnace-slag or scoria in being conspicuously cellular.

The above characters are not to serve as definitions, but only to aid in the selection of types.

The salient distinctive characters of fragments belonging to the above kinds of rocks, as thus described, are few in number: but the different masses, and even the different parts of a single mass, rarely, if ever, attain to this extreme simplicity and definiteness of character. Hence, it is really impracticable to give rigid *definitions* of kinds to which all the rocks met with in Nature can be referred; and it becomes necessary to *select particular rock-masses,* with which all others may be compared in respect of each of their characters: in other words, to select those rock-masses which are most different from each other in their characters, and use them as types to which others can be referred. The characters of any other rock-mass can then be defined by their relations to those of the types: the rock-mass will absolutely coincide in character with none of the types; but if the latter are satisfactorily chosen there ought to be one, and only one, to which any other rock-mass shows great similarity in the most important of its characters. The number of rock-masses selected as types should be as small as possible.

The distinctive characters already mentioned for various kinds of rocks are of value, not as furnishing definitions of the types, but as aiding us to select the particular rock-masses which may most advantageously be used as types.

Mutual relations of the above kinds of rocks.

We have seen that the rocks of the above seven groups have one or more important characters in common with each other: it is possible, however, that there may be other and still more important characters in which any one of these rocks is less closely related to the other members of the group, wherein it has been preliminarily placed, than to one or more members of a different group. For example, dolerite has been put in the fifth group with granite, because both rocks consist of distinct crystals of more than one kind of mineral without visible cement, and their structures present no directional lithical characters: on the other hand, dolerite might be put in the fourth group with basalt, on the ground that both are composed of the same minerals in the same proportion and essentially differ only in the sizes of the immediate constituents. Again, talc-schist has been put in the first group with gneiss by reason of the common foliate holo-crystalline structure: yet it is similar to the rocks of the second group in its simplicity of material.

Importance of those lithical characters which may possibly be related to the mode of origin of the rock.

Those lithical characters of a rock which may prove to be closely related to its mode of origin especially deserve to be minutely studied, and to be assigned great importance in the framing of a scheme of classification. It may be assumed that rocks which have been formed by the same kind of process will have various lithical characters in common, even when the rocks are different in mineral composition; but the converse is only likely to be true—namely, that rocks having certain characters of unknown origin in common have been formed by the same process—if the characters which are common to the rocks are both important and numerous, and none of the remaining characters are incompatible with such identity of process.

The same characters may result in different ways.

Even if two rocks are now absolutely indistinguishable in all their characters, it is still conceivable that the process, or series of processes, by which this result has been arrived at, may not have been wholly identical for both: two specimens of marble, for example, may be now identical in their characters and yet have originated in totally different ways—the one through simple chemical precipitation, the other through organic agency: the distinctive characters which belonged to the earlier stage of development—that of deposition—having been obliterated during the later stage—that of crystallisation.

Characters to be emphasised in the classification of rocks.

Still, although it is unsafe to infer that rocks have been formed by an identical process or series of processes, because they are now either indistinguishable in their lithical characters or at least have all the determinable lithical characters in common which they would have had if actually produced by that process or series of processes, it is advantageous that rocks having such characters in common should be brought together in the scheme of classification adopted. Such a classification is then really based on the present determinable characters, and not on any hypotheses as to the processes by which the rocks have been developed: but with a rock which has been produced by a particular process other rocks are associated, which, with our present means of investigation, are similar or even indistinguishable in their characters, whether they have been produced by the same process or not: the probability of identity of process is greater, the more numerous and distinct are the characters which are common to the rocks.

The modes of origin of the above kinds of rocks.

It is therefore desirable now to investigate how far the more evident characters of either the small fragments or the rock-mass itself suffice to suggest that the modes of origin of the above kinds of rocks are the same or different for the various members of each single group: we may then perhaps be able, by means of lithical characters alone, to frame a more natural and less overlapping scheme of classification than the one preliminarily suggested by those similarities of lithical character which appeal immediately to the unaided eye. The modes of origin, however, are in this case used merely to suggest the *degrees of importance* to be assigned to the several lithical characters, not as themselves furnishing a basis of classification.

MODES OF ORIGIN: *I. Crystalline schist, gneiss, slate, shale.*

(a). *Crystalline schist.*—The crystalline schists, whether simple or composite in mineral constitution, present so striking a similarity of general lithical characters that it is necessary to regard them as belonging to a single family, whatever views may be held as to their origin. Most of the crystalline schists, too, resemble each other in their stratiformity and in their associations with other rocks.

Gneiss.—With the same rocks are placed the gneisses, which are also rocks of foliate holo-crystalline structure, and are only mineralogically distinguished from the crystalline schists by the presence of felspar as an essential constituent. Common gneiss has the qualitative and quantitative mineral composition of common granite.

As mentioned later, the family of crystalline schists and gneisses is an artificial, not a natural one; for it has been established that the foliate structure of the rocks has originated in widely different ways.

(b). *Slate.*—Sometimes a slate contains fossils and in the mass the direction of original sedimental layers is still visible the direction of the latter being different from that of the cleavage: sometimes, notwithstanding a great contortion o the original layers, the cleavage has the same directio throughout the mass.

It is inferred that cleavage is a character due, sometimes a least, to a cause which came into operation long after th time of the original formation of the rock. The distortion o fossils by flattening out along the planes of the cleavag suggests that a violent pressure has been the inducing agent experiment has shown that such a cause is competent to communicate the property of cleavage, while earthquakes an earth-fractures, with the attendant contortions and fault indicate the actuality of the suggested cause.

Cleavage is thus inferred to be a secondary characte dependent on the action of a thrust and not on the mod of origin of the rock-mass itself: it may be expected t present itself in rocks of different modes of origin, and, a already pointed out, to be more conspicuously developed in fine-grained and less rigid mass than in one of coarse textu or one in which the particles are too much interlocked readily change their orientations; in fact, some slates we originally, not clay, but volcanic dust.

(c). *Shale.*—The identity of the chemical composition of shale with that of a mud deposited at the present day, t enclosure of fossils and the stratification, all indicate its sedimentary origin. The laminar fissility has the direction of the stratification: it probably results, partly from differences of mineral composition for the successive stages of deposit, and partly from changes in the positions of the constituent particles owing to the weight of the overlying matter.

As the directional lithical character has thus a possibly different origin in the case of crystalline schist, slate and shale, it is undesirable for the purpose of classification of kinds to lay very much stress on the mere fact of directionality of lithical characters, and we may be prepared to resolve the group into three: the directionality has been useful, however, in enabling us to bring together the rocks belonging to the several kinds; various rocks as being crystalline schists, others as being shales, still others as being slates.

MODES OF ORIGIN: *II. Rock-salt, hæmatite-rock, quartz-rock, calcite-rock, dolomite-rock, serpentine-rock.*

The probability is very strong that a rock composed essentially of a simple mineral has not resulted from the mere cooling of a molten mass; it is difficult to imagine that a molten mass occurring in Nature either could have or could long retain such simplicity of chemical composition; dunite, indeed, consists in great part of olivine and has consolidated from fusion, but chromite seems to be always present as an additional constituent. All unaltered rocks produced by known active volcanoes have been found to be essentially heterogeneous in their constitution, even if apparently simple.

But a large mass of material of essentially simple composition may have originated in various ways: for the deposition of the same kind of matter may be long continued, owing to the persistence of similar conditions as regards translation, evaporation, chemical precipitation, or the action of animals or plants; and the essentially homogeneous deposit may afterwards be altered by pressure, or heat, or percolating water, without becoming composite in kind of constituent material.

Or again, a large mass of essentially simple material may be a residue of a composite rock, which may itself have conceivably had any kind of origin: one mineral constituent of the original rock may have been susceptible of alteration into a substance of more permanent character; the others may have partly provided a chemical component for the actual residue, and partly given products capable of removal from the residue by percolating liquid.

The shape of the altered mass, the presence and relations of veins branching from the main body, and the position of the mass relatively to adjacent stratified rocks, may suggest a probable mode of origin of the original unaltered rock.

Though simplicity of mineral constitution is useful as a means of distribution of rocks into kinds, it cannot be taken as the basis of a *natural* group of kinds; for the other characters and the modes of origin of the rocks consisting of a single mineral are very different: on the other hand, simplicity is a very definite and a directly observable character, involving no speculative hypothesis, and is thus convenient as a basis for a group in an *artificial* scheme of classification.

MODES OF ORIGIN: *III. Coal, clay, obsidian, phonolite, felstone.*

These rocks have in common such a fineness of texture that the essentiality of the compositeness is concealed from the unaided eye: but apparent simplicity, like actual simplicity, is unsatisfactory as the basis of a group, for the other characters of these rocks are widely different, and it is desirable to at once break up the group into four others.

(a). *Coal* was early recognised to be a product of alteration of vegetable matter: only in the extreme case does evidence of the original organised structure completely disappear.

(b). *Clay* is always a product of alteration, and there is never any doubt as to its sedimentary origin.

(c). *Obsidian*, from its likeness to artificial glass and its occurrence as stream-shaped masses near active volcanoes, was soon known to be a natural glass, a product of volcanic action: it may thus be expected to be really a mixture of chemical compounds.

(d). *Phonolite* and *felstone,* whatever their mode or modes of origin, are quite distinct in their general characters from coal and clay: not being really simple mineral species, they approach closely to the members of the following group.

MODES OF ORIGIN: *IV. Rhyolite, trachyte, andesite, basalt.*

The general similarity of characters suggests that the mode of origin, whatever it may be, is common to all members of the group.

MODES OF ORIGIN: *V. Granite, syenite, diorite, dolerite, euphotide.*

As in the case of the last-mentioned group, the general similarity of the characters suggests that this also is a natural one, whatever the mode of origin of the rocks may be.

MODES OF ORIGIN: *VI. Breccia, conglomerate, sandstone.*

It is easy to see that rocks belonging to this group may have originated in different ways: the kinds of material aggregated, the agents of aggregation, the agents and amounts of fracture, the kinds and amounts of cementing material, the amount of subsequent alteration, may all be various.

In one prominent set of cases, for example, small fragments of disintegrated pre-existent rock have been transported from a distance by flowing water, deposited, and cemented together. In another prominent set of cases, again, fragments torn from molten lava have been shot into the atmosphere by escaping steam, deposited as a shower of dust, and cemented together through the action of percolating rain-water.

MODES OF ORIGIN: *VII. Lava.*

Lava is the name given to the molten matter which flows from a volcanic vent.

A nearer approximation to a natural system of classification.

With the above in mind and still having regard only to the more obvious characters, we may now consider what alterations will diminish the overlapping of the groups, and bring nearer together the rocks which have a close similarity of all their more important characters; such a system, if perfect, would be a *natural* system of classification. The following suggests itself as a nearer approximation to a satisfactory grouping of the above rocks by means of actual characters capable of direct determination. We must remember that a perfect scheme of classification should make it possible, among other things, to assert a general proposition relative to the members of each group, and that the proposition should relate to a property different from those which have served for the definition of the group.

I. Rocks consisting essentially of compounds of carbon and hydrogen.

COAL.

These rocks form a natural group: they are combustible: they have had a vegetable origin.

II. Rocks consisting essentially of a single mineral.

ROCK-SALT, HÆMATITE-ROCK, QUARTZ-ROCK, CALCITE-ROCK (CHALK, LIMESTONE, MARBLE), DOLOMITE-ROCK, SERPENTINE-ROCK.

This is an artificial group: no common property other than simplicity can be asserted of its members; except that it is improbable that a simple rock has consolidated from the molten state and has remained unaltered. Many different modes of origin are represented by these rocks.

The group being merely one of convenience, any of its members may, if convenience requires it, be transferred to another group with the members of which it has a different and more important character than simplicity in common.

III. Rocks showing aggregate structure but not cleavable.

BRECCIA, CONGLOMERATE, SANDSTONE: CLAY: SHALE.

This is a natural group, but capable of sub-division according to the agents of aggregation, amount of fracture, and so on. A common proposition is that most of the immediate constituents of each rock-mass have previously been in different relative positions from those now occupied.

IV. Cleavable rocks.

SLATE.

This is another natural group. The basis of the group is the character of cleavage; a common proposition is that all the rocks belonging to it have been subjected to a violent thrust in a direction perpendicular to that which has become a direction of cleavage. There may be sub-division of the group, suggestive of the history of the rocks before the compression.

V. Rocks which are holo-crystalline in structure and show a directionality of the lithical characters.

CRYSTALLINE SCHISTS, GNEISSES.

As already remarked, this is an artificial, not a natural group; in some cases the directionality of the lithical characters is due to a cause which came into operation subsequently to the formation of the original rock, and such crystalline schists include rocks which originated in different ways; in some other cases, the directionality is a result of flow of a crystallising molten rock. The rocks which consist of a single mineral and have the characters of this group may be conveniently transferred to it.

VI. Rocks which consist of more than one kind of mineral, are holo-crystalline in structure, and show no directionality of the lithical characters; the ground-mass of the porphyritic kinds not being of extremely fine texture.

GRANITE, SYENITE, DIORITE, DOLERITE, EUPHOTIDE.

Notwithstanding the diversity of mineral character of these rocks, this is probably a natural group, whatever the mode or modes of origin. So general and comparatively uniform a distribution of the various minerals throughout a large volume can scarcely be imagined to have resulted in any other way than by crystallisation from a uniform viscous mass. There may have been changes, however, subsequent to the original crystallisation; the hornblende of some diorites, for instance, has resulted from the alteration of the less stable mineral, augite.

VII. Rocks in which there is a ground-mass with porphyritic enclosures; the ground-mass being of extremely fine texture.

(*a*). PHONOLITE. (*b*). FELSTONE. (*c*). RHYOLITE, TRACHYTE, ANDESITE, BASALT.

This apparently natural group is immediately sub-divisible into three subordinate groups according to mineral composition. As in the case of the last group, it seems impossible to imagine that a rock with such a structure can have been formed in any other way than by the crystallisation of a viscous mass.

In the case of the marble of Tiree, crystallised material (marble) encloses porphyritically-dispersed crystals of another mineral (diopside), and the structure has no directionality: such a rock can be excluded from the two last groups by means of the statement that the enclosed crystals of diopside are not *essential* to the kind.

VIII. Rocks which are cellular or of vitreous structure.

LAVA, OBSIDIAN.

These rocks have been expelled in a molten state from volcanic vents, and form a natural group.

Processes by which rocks have been formed and have attained their present characters.

Preparatory to the discussion of the probable modes of origin of the rocks belonging to the basalt, granite and crystalline schist groups, respectively, it will be well to have before us a statement of the various processes of rock-formation (including rock-alteration) which we know from observation or inference to be going on at the present day.

I. Deposit of dissolved matter through evaporation or cooling of a solvent.

An inland sea or lake, without outlet, and so situated that the water lost by *evaporation* is on the average greater in quantity than that which enters it, must eventually reach the condition of saturation: after this epoch there will be a gradual deposition of solid matter; in general, crystallised matter, since the process is necessarily a slow one. The point of saturation being different for different dissolved salts, the first salt deposited will be pure. The water of the Dead Sea is extraordinarily rich in dissolved salts, chiefly chlorides of sodium and magnesium: 100 pounds of the water contain 25 pounds of salts, while the same weight of ordinary sea-water only contains between 3 and 4 pounds of dissolved matter.

The siliceous encrustations from hot springs, such as those of Iceland or Yellowstone Park, U.S.A., illustrate the deposition of matter through the *cooling* of a solvent.

II. Deposition from liquid by reason of chemical reactions.

(a). *Without intervention of organisms:* as in the precipitation of an insoluble substance resulting from the interchange of the bases of two soluble salts.

(b). *With intervention of organisms:* as in the separation of calcium carbonate from water by coral animals, or of silica from water by diatomaceous plants.

III. Cooling of molten rock.

In the case of the molten rock of an active volcano, there are different circumstances of cooling for different portions of the molten mass—the outflowing stream, the material filling the vent or fissure, the material which is intruded into the rocks surrounding the vent, the material in the reservoir itself. The part which cools most quickly will tend to be glassy in structure. At a high temperature, the tension of saturated steam is enormous, and a small weight of water, if converted into steam at the temperature of molten lava, will thus expand to an immense volume unless restrained by external pressure: hence, near the surface of a stream of steam-containing lava which has been extruded from a considerable depth, the viscous mass will contain numerous cells which have been distended through the expansion of the entangled steam as the height of the superincumbent lava, and therefore also the pressure, have diminished; this cellular character it will retain to some extent after cooling and solidifying; the cells will be elongated in the direction of flow of the viscous mass. In the interior of the stream the pressure due to the weight of the lava above will oppose this great expansion, and the cells will be correspondingly smaller: further, the heat will escape much more slowly from the interior than from the parts near the surface, and, owing to the long-continued viscosity of the surrounding lava, the cells may slowly collapse as the temperature falls and the vapour-tension diminishes; the cooled material of the interior will also be less glassy in character than that of the superficial portion of the stream

More especially will this be true for those portions of molten rock which remain in the vent, or are intruded into the neighbouring rocks, or remain in the reservoir. Further, it is reasonable to expect that, in a long-continued volcanic action, the slow and partial crystallisation of the contents of the reservoir may produce a gradual change in the percentage composition of the still molten material contained therein, and therefore also of the extruded lava. By reason of the occasional disturbances within a volcanic vent, crystals may be carried to other positions in the molten mass, and be corroded or even broken by the action of the surrounding molten material. Molten rock, which has been longer exposed in the vent to the action of the ascending vapours, may eventually differ in character from the rest of the material. Experiment teaches us, too, that the fluidity of a mass at a given temperature is dependent upon the pressure to which the mass is subjected: mere diminution of pressure as a result of the outflow of lava may thus hasten the crystallisation of the residual molten material.

IV. Extrusion of a mud.

Matter extruded on a large scale from a vent in the earth's crust is sometimes a mud, which solidifies and becomes a coherent rock.

V. Aggregation of transported constituents.

Fragmentary mineral matter may be aggregated into large masses after transportation through

(a). *The simple action of gravity.* Example:—a mass of aggregated fragments at the base of a cliff; the support of each fragment having been removed by the action of wind, or of flowing or freezing water.

(b). *Air in motion.* Examples:—sand-dunes or desert-sand.

(c). *Steam in motion.* Example:—the material ejected into the atmosphere from a volcanic vent by escaping steam, and afterwards deposited.

(d). *Water in motion.* Examples:—the material aggregated by tidal action or deposited in the bed of a flowing stream, or more slowly over a considerable area from an overlying sea, or lake, or a river which has overflowed its banks.

(e). *Ice in motion.* Example:—glacial moraines.

The sizes, rounded or angular forms, the mineral constitution, and the mode of arrangement of the aggregated matter, will generally suggest the particular agent of transport.

VI. Inclusions.

Mineral, vegetable and animal material may be accidentally included within a rock-mass during its formation, and evidence of the inclusion may remain.

VII. Alterations.

Vast alterations may be produced in a rock-mass in various ways:—

1. *By the mechanical and chemical action of air and water on the superficial portions;* as in the case of disintegration by ordinary "weathering." Such portions are rendered more accessible to the above agents by the fractures of the rock which result from the expansion of freezing water.

2. *By the percolation of hot or cold liquids and vapours through the mass;* more especially in the neighbourhood of volcanic vents. A firm mass may be disintegrated, or loose fragments may be firmly bound together: the extent of the action will depend on the mineral composition of the rock, on the accessibility of the internal parts to the percolating matter, and on the nature of the percolating fluid.

3. *By chemical alteration throughout.* The original mass may have been inorganic: for instance, it is inferred from observed characters that some masses of serpentine have resulted from the chemical alteration of a rock containing much olivine. Or the original mass may have been organic: it is

inferred that a seam of coal has resulted from the chemical alteration of a layer of vegetable matter.

4. *By the intrusion of a hot molten mass.* The change will be partly due to the high temperature, partly to the vapours which are introduced with the molten rock.

5. *By the application of enormous pressures.* The rock may be made more compact, be ground into fragments, or be contorted: experiment shows that both cleavage and joint-planes may be communicated to matter by the action of a stress, and that bodies enclosed in a more yielding material will rearrange themselves so as to have their longer edges or broader sides perpendicular to the direction of the pressure; further, chemical interchanges may result from the greater proximity of the particles or the change of temperature induced by the stress.

Modes of origin of various rocks.

So far, no definite assertion has been made above relative to the modes of origin of the rocks belonging to the basalt, granite and crystalline schist groups, except that basalt and granite would appear to have resulted from the crystallisation of a uniform viscous material: further, it will have been remarked that, although the interior of a cooled lava-stream is known not to be necessarily cellular, only obsidian and undoubted lavas, which form a very minute proportion of the earth's crust, have been above recognised to have originated as molten rock. In this regard, among the questions which immediately suggest themselves are the following:—Of the accessible rocks is it possible that only obsidian and the lavas of still active volcanoes have consolidated from a state of fusion? Did volcanoes exist during such of the early stages of formation of the earth's crust as are represented by the older of the accessible and undoubtedly sedimentary deposits? Have any of the rocks of the basalt, granite and crystalline schist groups consolidated as ejected lava-flows, or in vents, or as intrusive masses, or in reservoirs?

The mode of origin of basalt.

For many years, violent controversy raged round the question of the origin of basalt: by one party of mineralogists, basalt was held to be a marine sedimentary deposit, by another party, a product of volcanic action. Through increased observation and experiment the controversy has been brought to an end: since, however, the question of the origin of basalt was regarded as a critical one for a whole group of rocks and the continuance of the controversy had a vast influence on petrological study, it is instructive to review in some detail the facts and reasoning by which it was possible for two such entirely different views to be widely supported.

In various countries, basalt occurs in stratiform masses between beds of undoubtedly marine origin; in other places, as caps on the tops of isolated hills, so similar in height that the caps may be reasonably inferred to have once belonged to a continuous layer: lava on the other hand was said to only occur in stream-form masses, not in large sheets. Like gypsum, marl and sandstone, none of them of volcanic origin, basaltic masses are often columnar in structure, as is so well shown at the Giant's Causeway and Fingal's Cave: the lava of a modern volcano rarely, if ever, shows such a structure. Further, basalt is not cellular like lava: some of its enclosed minerals are fusible at the temperature of molten lava and would presumably have assumed the glassy condition on cooling: sometimes basalt encloses zeolites or chalcedonic nodules containing water, minerals which were thought to be incompatible with a former high temperature of the rock. Again, basalt was said to be distinct from lava in showing no signs of vitrification and in not being associated with volcanic scoria and dust: also it has been found in contact with unaltered coal. It was further asserted that no basalt has been formed since the beginning of the Tertiary Epoch. For a time, too, it was supposed that fossil remains had been found in basalt; but the fossil-bearing rock, though like basalt in its colour and fine texture, was afterwards shown to be completely different therefrom in its other characters.

But if we only concede that molten rock can have taken the form of an extensive sheet, none of the above statements, so far as they are correct, are inconsistent with basalt having originated at a high temperature, while other facts are quite incompatible with a sedimentary origin.

The most decisive fact is that basaltic masses, intercalated between undoubted marine sedimentary deposits, sometimes throw out veins or break through one or more of the sedimentary layers, and then again follow the direction of the bedding; other basaltic masses have the form of enormous dykes or walls which break through stratified layers: such rocks must have been intruded in a molten condition. A basaltic mass intercalated between two beds of marine origin may thus be either of intermediate age or junior to both. At Ardtun, in the Isle of Mull, the lower bed had existed for a time as dry land before it was covered with the basalt, for between the basalt and the lower marine deposit there is a layer containing leaves which are found to be those of land-plants. The capping of hills with basalt is consistent with either view: enormous denudation is supposed to have taken place, and the compactness of the basalt has here and there preserved the inferior beds of less compact material from being washed away. The columnar structure of basalt, again, is not identical in character with that of the sedimentary deposits: the columns are not continuous throughout their length, but are jointed; and the joints have occasionally very peculiar forms (ball-and-socket joint, mortice-and-tenon joint) never yet met with in undoubtedly sedimentary rocks. Nor has the formation of basalt been confined to pre-Tertiary times: the leaf-beds of Ardtun already referred to are of Tertiary age, and the overlying basalt must be younger than the leaves: indeed it is now inferred that all the basalt of the western part of Scotland and the northern part of Ireland is really of Tertiary age, and that its occurrence between deposits of Secondary age is wholly due to intrusion.

It being established that *some* masses of basalt have originated as molten rock, it follows that the characters which were asserted to be only consistent with a sedimentary origin must be really consistent with the other view: the difficulty is no longer to decide as to the mode of origin of basalt, but to discover how the different characters can have been acquired.

Although basalt has not the vitrified aspect of an ordinary lava, it is found on microscopic examination of a thin section to contain glassy particles suggestive of a former molten condition: if basalt be fused and quickly cooled, a glass results, but as the duration of the cooling is prolonged the product becomes more and more stony in character; it has now been experimentally shown that by proper management of the cooling a material having the mineralogical and structural characters of basalt can be reproduced. While the columnar structure of gypsum, marl and sandstone is due to shrinkage consequent on the loss of moisture, that of basalt is held to be due to shrinkage consequent on the cooling of the molten mass: and the positions of the columns are related to the surfaces which would be most exposed to cooling influence.

The cellular structure of ordinary lava is due to the expansion of imprisoned steam: the size of a cell in the molten rock itself depends on several things—more especially on the amount of enclosed steam, the temperature and viscosity of the lava, and the pressure at the part where the cell is formed; that the cell may continue its existence till the rock has cooled, the lava must solidify while the pressure of the steam is sufficient to withstand the external pressure. The amount of water necessary to produce vesiculation under ordinary atmospheric pressure is trivial: it has been calculated that only 0·0001 per cent. by weight, a percentage beyond the estimation of the chemical analyst, is required to produce at the ordinary atmospheric pressure vesicles amounting in volume to 40 per cent. of that of the mass, and that 0·000,000,007 of a cubic inch of water will give sufficient steam to fill a cavity of the mean size ($\frac{1}{35}$th of an inch in diameter). Under the pressure of several hundred or thousand feet of superincumbent material no vesiculation could take place; and indeed the vesicles are found to be generally small, even in the middle of a lava-stream of comparatively small depth: hence, in any case, we could expect little vesiculation in the case of a lava of a viscous nature; and no vesiculation at all in the case of dykes or intrusive sheets except in those parts which were near to the earth's surface at the time of the intrusion. Not only the upper but also the lower part of a lava-stream is cellular; observation shows that the latter cellularity is a result of the former, for the scoria on the front and outer part of an advancing stream continually falls down and is covered by the flowing lava: this scoria then becomes the lower part of the stream, communicating thereto the cellularity which it has itself retained.

The enclosed zeolites and chalcedonic nodules containing water are explained as secondary products deposited in the cavities by percolating liquid, which has extracted the necessary materials in its passage through the rock.

The absence of volcanic scoria and dust may be accounted for in either of two ways: first, the basalt may have been intrusive, while scoria and dust are only sub-aerial products of volcanoes: or again, the scoria and dust, being less coherent and more easily decomposed than the basaltic sheet, may have been removed by subsequent denudation. But it is now known that scoria and dust are not always completely absent: they are sometimes still distinctly recognisable, though much changed in aspect since the time of their ejection: in the Western Isles of Scotland, for example, not only are volcanic scoria and dust both recognisable, but even the fact that the condition of the parts near the upper and lower surfaces of the basaltic sheets was originally vesicular is still manifest.

The irregularity of the action of the molten basalt upon the material with which it has come into contact is perhaps greater than would have been expected, but it must be remembered that the surface of the molten rock will be immediately chilled by the contact with cold material, and that a solid non-metallic material is usually an extremely bad conductor of heat. It may be mentioned, as an illustration of the possible differences of temperature at points very near to each other, that it is sometimes practicable to escape imminent destruction by a flowing lava-stream by walking over the scoria on the surface; again, snow which has been covered by a stream of molten lava has been found as ice beneath the cooled rock many years after the volcanic eruption has ceased.

There is no reason to believe that basalt has been formed in more than one way.

The characters and modes of occurrence of basalt, andesite, trachyte and rhyolite are so similar that we may assert a common mode of origin for all.

The mode of origin of granite.

It was soon noticed that the percentage chemical composition of a granite is the same as that of a rhyolite, and that the limits of variation are the same for the two kinds of rock; whence it follows that granite and rhyolite would, on fusion, now yield identical products. Those earlier mineralogists who asserted the volcanic origin of rhyolite sought to account for this identity of chemical composition by the hypothesis that a rhyolitic lava-flow is actually produced by the fusion of neighbouring granite, the latter kind of rock being then regarded as one of the oldest of the earth's crust and as belonging wholly to the Primary Epoch. Such a hypothesis would provide a source and account for the mode of origin of rhyolite and the chemical relationship of the two rocks, and yet involve no hypothesis as to the mode of origin of granite itself. Later, on other grounds, more especially the branching of veins from a main mass, and the variation in the lithical characters and in the direction of the layers of the adjacent sedimentary deposits when the surface of junction with the granite is approached, those who asserted the volcanic origin of rhyolite also claimed that granite itself has cooled from a state of fusion.

On the other hand, it was objected that no granite has been found among the products of active volcanoes, and that no known masses of granite have the stream-shapes characteristic of lava-flows: more especially, it was urged that granite could not have resulted from the cooling of a fused product seeing that fused quartz solidifies at a higher temperature than fused felspar, whereas the felspar of granite, being usually the more completely developed constituent and determining the form of the quartz, must really have been the first to consolidate. This latter objection is now known to be based on wrong premises; for the order of the crystallisation of different salts from a mixed solution is found on experiment to depend, not merely on the temperature, but on the nature of the solvent: the orders of crystallisation of quartz and felspar separately fused, and of quartz and felspar which have to crystallise from a fused mixture of silica and silicates are not necessarily the same, and in fact are different.

This difficulty as regards the order of the crystallisation of the quartz and felspar being thus removed, it has been suggested that the difference between rhyolite and granite is solely due to the difference of the circumstances of the cooling of the same kind of fused material; that the same fused product may yield rhyolite or granite according as the cooling takes place under comparatively small pressure and in a comparatively short time, as in the case of lava-streams, or under enormous pressure and with extreme slowness, as would necessarily be the case for the material left in the reservoir from which the lava-streams themselves have issued. This suggestion would likewise account for the fact that granite is generally found only among the oldest rocks: for the occurrence of granite at the surface of the earth's crust would only take place when denudation has removed the enormous mass of superincumbent material to which the enormous pressure was directly or indirectly due, and therewith also the lava-streams which had their source in the now granitic reservoir. Further, any reservoir yielding a rhyolitic lava-flow and now in process of cooling must be so far below the surface as to be inaccessible to observation: by the time that the consolidation to granite is complete and the rock is accessible, probably all the present sub-aerial evidences of the existence of this mass of molten material will have been removed.

That granite has been really formed under circumstances of great pressure is indicated by the presence, in its mineral constituents, of cavities containing liquid carbonic acid.

Rocks which have originated in this way are said to be of *plutonic* origin.

Other kinds of rocks with the chemical composition of granite and rhyolite.

Although, having regard to the enormous differences in the rates of cooling of the different parts of a large molten mass, we have thus no right to expect to *discover* a single cooled mass now showing in its different parts the characters of granite and rhyolite respectively, yet, having regard to the degree of constancy in the chemical composition of the granites of various countries, we should expect to find in different localities rocks, which have presumably cooled down from a state of fusion, presenting the chemical composition of granite but yet different kinds of structure even additional to those of granite and rhyolite. That this is actually the case is shown by the following analyses of granite, rhyolite, quartz-felsite (one of the felstones), and obsidian:—

	Granite.* *Co. Dublin.*	Rhyolite.† *Styria.*	Quartz-felsite.‡ *Bohemia.*	Obsidian.§ *Mexico.*
Silica	73·00	73·39	74·21	73·63
Alumina	13·64	14·12	13·37	14·25
Ferric oxide . . .	2·44	0·77	—	—
Ferrous oxide . . .	—	0·67	1·94	1·80
Magnesia	0·11	0·29	0·46	1·42
Lime	1·84	1·25	1·00	—
Soda	3·53	3·66	3·56	4·61
Potash	4·21	4·47	4·15	4·39
Loss on ignition . .	1·20	1·22	1·18	—
	99·97	99·84	99·87	100·10

* "Quart. Jour. Geol. Soc.," 1856, vol. 12, p. 177.

† "Mineralog. Mittheil." [Tschermak], 1877, p. 276.

‡ "Ann. d. Chem. u. Pharm," 1853, vol. 87, p. 332.

§ "Comptes Rendus," 1865, vol. 61, p. 317.

From the close similarity of these percentage chemical compositions, it may be inferred that if a single mass, after cooling from fusion, could present in different parts the characters of granite and rhyolite respectively, other parts of the same mass might be expected to present the respective characters of quartz-felsite and obsidian, if rocks belonging to these latter kinds have likewise consolidated, as suggested above, from the viscous condition.

Only rocks which have suffered inappreciable alteration should be compared in this way.

But we can only infer that certain rocks, originated by way of fusion, must have had the same percentage chemical composition at the *times of fusion* because they have an identical chemical composition *now*, if we can legitimately assume that each of those rocks has had no chemical constituents added or removed during the long ages which have elapsed since the epoch of the solidification. It is thus useless, for the present purpose, to compare together the chemical compositions of those rocks which have suffered evident alteration.

The gabbro, dolerite, basalt and tachylyte series.

But we know, from experiment, that different kinds of fused products differ considerably from one another in their readiness to yield a glass or well-developed crystals on cooling, and that chemical compounds differ from each other in the facility with which they suffer decomposition; we could thus only expect to find two kinds of rocks, having the same relations to basalt that obsidian and granite respectively have to rhyolite, if the mixture produced by the fusion of basalt is as ready as fused rhyolite to give a glass or a holo-crystalline rock under corresponding circumstances of cooling, and if the resulting rocks are equal to obsidian and granite in resisting power to terrestrial decomposing agents. But this is not the case;

in the manufacture of glass it is found necessary to prepare a mixture in which the alkalies are present in greater proportion than characterises basalt. A series in some respects analogous to the granite, quartz-felsite, rhyolite and obsidian series, but having the same percentage chemical composition as basalt is, however, actually known, namely, *gabbro* * (a holo-crystalline rock consisting largely of felspar and augite), *dolerite, basalt* and *tachylyte* † (basalt-glass, more easily fusible than obsidian or rhyolite-glass): one important difference is, that the unaltered rock gabbro, corresponding to granite, is a comparatively rare one, for augite is very liable to alteration to diallage. The various stages of the change from augite to diallage which have taken place can in fact be traced with the microscope; the altered rock, diallage-gabbro, in which this change has taken place, is more common than unaltered gabbro itself: when the felspar has likewise been much altered and has been changed to the white, nearly opaque, mineral aggregate once thought to be a definite mineral species and named "saussurite," the rock is termed a saussuritic gabbro, or *euphotide* (Haüy): these alterations are not superficial and due to mere "weathering," but extend throughout masses of very large dimensions. Tachylyte, again, is not known in large masses like those of obsidian; it generally occurs as a mere crust on the outer part of a mass of basalt.

Further, the great readiness of a molten mass having the chemical composition of a gabbro or basalt to yield crystallised products on cooling, has for result that the intermediate term dolerite is more nearly related both to gabbro and basalt than the intermediate term quartz-felsite is to either granite or rhyolite. Although under particular circumstances of cooling gabbro, basalt or tachylyte may result, a comparatively slight deviation from those circumstances causes the solidification of the molten material as dolerite.

---

* *Gabbro,* an Italian name.

† *Tachus,* quick; *Lutos,* dissoluble: because of its easy fusibility.

Analogous series corresponding to intermediate members of the rhyolite—basalt group.

And we may infer the probable existence of similar complete or partial series of rocks corresponding to every member of each of the rhyolite, trachyte, andesite and basalt kinds; the difficulty is to find external characters which may serve for their discrimination: for, just as it is impossible to decide on the position of a natural glass relatively to obsidian and tachylyte by reference to the more evident characters alone and regard must be had to some character, such as fusibility or percentage chemical composition, requiring experiment for its determination, there is also a practical difficulty in deciding the exact relations to each other of other rocks of the various series. We may say, in the first place, that trachyte is related to syenite, and andesite to diorite, in the same way that rhyolite is related to granite and basalt to gabbro. In the next place, quartz-felsite is a member of a set of rocks in each of which porphyritic constituents are dispersed through a finely crystalline ground-mass; and just as quartz-felsite may be regarded from a certain point of view as structurally intermediate between the more coarsely crystalline of the granites and the mero-crystalline rhyolite having the same percentage chemical composition, so other rocks of fine texture and containing porphyritically-dispersed crystals are intermediate between syenite and trachyte, and also between diorite and andesite, respectively. The following table thus brings near together various rocks which are closely related to each other in composition and structure and probably in one, at least, of their possible modes of origin :—

Granite	Quartz-felsite	Rhyolite	Obsidian
Syenite		Trachyte	
Diorite		Andesite	
Gabbro	Dolerite	Basalt	Tachylyte.

The position to be assigned to phonolite in the scheme of classification.

In the above scheme of classification, phonolite has not yet been assigned a place. We have already seen that this rock stands mineralogically apart, notwithstanding its structural similarity to the members of the rhyolite—basalt group: for while the members of that group were regarded as essentially having the same kind of mineral constituents (felspar and augite, with or without quartz), and as having chemical compositions such as would result from the admixture of two extreme members of the group in different proportions phonolite was known to be distinct from them in containing an additional essential constituent, nepheline, in considerable quantity. But nepheline, although not a felspar, and indeed quite unlike the felspars in crystalline form, is a member of a small group of minerals, conveniently termed *felspathoids* which are very nearly allied to the felspars in chemical composition: having regard to the average chemical composition of the mass, we may thus regard phonolite as allied chemically to trachyte, and the felspathoid constituent (nepheline) as related to phonolite in the same way that the felspathic constituent is related to trachyte.

Felspar-less rocks related to the above class.

It is seen that for every kind of holo-crystalline or mero-crystalline rock belonging to the last-mentioned class, felspar of some kind or other is an essential constituent: but other rocks, limited in the frequency and the extent of their occurrence, so far resemble the holo-crystalline and mero-crystalline members of this group in their structure and general characters that they are conveniently associated with them, notwithstanding the fact that both felspars and felspathoids are conspicuously absent from their mineral composition: free silica (quartz or tridymite) is likewise absent. At least one of the following minerals is present:—olivine, enstatite, augite, hornblende, biotite; all being silicates in which iron and magnesium are important constituents. For rocks consisting essentially of these minerals the proportion of the bases to the silica is greater than for those which contain felspar or quartz: the rocks are thence often termed *ultra-basic.* Of these may be specially mentioned a set of rocks called *peridotites* by reason of the presence of olivine (or peridot) as an important mineral constituent; the most distinct in kind are:—

Dunite,[*] consisting essentially of olivine and chromite,
Saxonite,[†] of olivine and enstatite,
Lherzolite,[‡] of olivine, enstatite and augite,
Picrite,[§] of olivine and augite or hornblende.

Most of the rocks of this set are granitic in structure, but some varieties of picrite have the structure of trachyte.

The modes of origin of the crystalline schists.

The group of the crystalline schists, as already pointed out, is artificial, and includes rocks of which the common character, the foliate holo-crystalline structure, is due to widely different causes. And for no other rocks has there been so much speculation as to the mode or modes of formation: indeed, only in comparatively few cases has the mode of origin of a crystalline schist yet been satisfactorily established. The other characters of a crystalline schist indicate in most cases that the foliate structure is of *secondary* origin, this and other characters having been developed since the existence as a rock-mass began; the original mass may have been violently

---

[*] Named after Dun Mountain, New Zealand.

[†] Named after Saxony.

[‡] Named after Lake Lherz in the Pyrenees.

[§] *Pikros,* bitter: because of the proportion of magnesium, of which the sulphate (Epsom salt) has a bitter taste.

349689

crumpled, or even broken and faulted, while further a well-distributed stress may have had for result a general deformation and fracture of the individual constituents throughout a large part of the mass: for example, in the coast-ranges of California, where crystalline schists are never far distant from each other though always of less than ordinary dimensions, the disruption has been so general that the largest unfissured mass in the whole area is said to be probably not more than one or two inches in diameter. Again, at a comparatively late stage in the history of a rock which is now schistose, new crystallised mineral constituents have been sometimes formed by molecular interchange, or old, perhaps broken, crystallised constituents have resumed their growth. There may thus be great practical difficulty in inferring either the original characters of the rock or the processes by which the present foliate structure has been arrived at.

Sometimes, however, the foliate structure is an *original* character of a rock which has itself resulted from the consolidation of intruded molten material: the directionality being due to a slow relative motion of the parts of the crystallising mass, and probably related also to the direction of the pressure under which the cooling and the crystallisation have taken place.

The effect of later research on the classification of rocks.

So far, for the sake of simplicity, we have laid stress in the classification of rocks only on the methods of investigation which were known to the earlier petrologists, and then sufficed for the recognition of kinds to which the above names were assigned. The application of the microscope to the investigation of thin rock-sections by means of transmitted polarised light has been of immense help to the petrologist: he has thus been enabled to determine, with a precision previously not dreamed of, the mineral composition and structure and the general characters of rocks, or parts of rocks, which are of too fine a grain to be resolved in any other way: more especially, the microscope has been useful in rendering it possible to establish the presence of glassy constituents in those rocks, or the fragmentary or crumpled form of the minute component particles, or the optical characters of the constituent felspars.

Yet this refined mode of investigation and the continued researches of the chemists have had comparatively little influence on the ideas as to the characteristic features of the *kinds* themselves; so much is this the case that it is possible to obtain a general notion of the features of the more important of the now recognised kinds without any great departure from the modes of classification suggested by the earlier methods of investigation.

Pyroxenes, amphiboles, micas.

It must, however, be remarked that augite and hornblende are so nearly alike in chemical composition that it was impossible to distinguish between them, when present as minute constituents, before the microscopic examination of transparent rock-sections had been introduced. Further, it is now known that, whereas augite and hornblende crystallise in the mono-symmetric system, other minerals having the same chemical composition and very similar characters and associations crystallise in the ortho-rhombic system; it is found convenient to designate the groups of minerals allied to augite as ortho-rhombic and mono-symmetric *pyroxenes,* and those allied to hornblende as ortho-rhombic and mono-symmetric *amphiboles.* Also, the pyroxenes and amphiboles are chemically related to biotite, a member of the mica group, in that they are silicates in which iron and magnesium are present in large proportion.

Hence we are prepared for the fact that some of the "augite" of the early investigators, instead of being truly augite, is in some cases hornblende, in others orthorhombic pyroxene (enstatite); further, we must be ready to recognise that rocks which contain augite or hornblende may be closely related to other rocks in which biotite plays a prominent part.

Granites.

Case XI. Beginning with those holo-crystalline rocks which are without directionality of lithical character, granites are those in which the constituents quartz and potash-felspar (orthoclase or the closely allied felspar microcline) are essential, and mica is normal.

The more important kinds of granites are the following:—

- *Muscovite-granites:* in which only one kind of mica, muscovite, is present.
- *Biotite-granites:* in which only one kind of mica, biotite, is present.
- *Muscovite-biotite-granites:* the mica being of two species, muscovite and biotite.
- *Hornblende-granites* and *hornblende-biotite-granites:* hornblende playing the part of either the whole or a portion of the mica.
- *Augite-granites* and *augite-biotite-granites:* according as the augite takes the place of the whole or part of the mica.
- *Haplites*: only quartz and potash-felspar being present.

Case XII. The *granite-porphyries* form a link between granites and quartz-felsites, the ground-mass being intermediate in texture between that of porphyritic granite and that of quartz-felsite.

Syenites.

Case XIII. The syenites are now differentiated into *hornblende-syenites* (or syenite proper) and *augite-syenites* (or monzonites*), according as the mineral which accompanies the orthoclase is hornblende or augite.

Mica-syenites and *mica-hornblende-syenites* are allied rocks in which mica (biotite) takes the place of the whole or part of the hornblende.

Nepheline-syenites are holo-crystalline hornblende-orthoclase rocks, and differ from syenite proper in containing elæolite, a variety of nepheline, as an important additional constituent. Case XIII. Nepheline-syenites containing zircon as an important accessory constituent have been termed *zircon-syenites.* The nepheline-syenites of Miask in the Urals, Ditró in Transylvania and the Foya Mountain in south-west Portugal have been named *miascite, ditroite* and *foyaite,* respectively.

---

* *Monzoni*, a mountain in Southern Tyrol.

Diorites.

The close relationship of the syenites and diorites, as being Case XIV. felspar-hornblende rocks of holo-crystalline structure, is manifest; it has already been remarked that whereas in syenites the felspar is orthoclase, in the diorites the felspar is plagioclastic (lime-felspar or lime-soda-felspar). According as the ferro-magnesian silicate is hornblende or biotite, the rocks are termed, if quartz is absent, *hornblende-diorites* (or diorites proper) or *mica-diorites.*

There are quartzose rocks related to the hornblende-diorites and mica-diorites in the same way that the hornblende-granites are related to the syenites, and it has been proposed that the name *tonalite,** initially used in connection with a particular rock-mass, should be applied to the whole of the quartzose group: owing to the presence of quartz in some parts and its absence from other parts of the same mass, it is more convenient to keep the rocks in the same division, and to retain the term diorite as part of the name of the rock even when the rock-mass is quartzose.

Gabbros and norites: dolerites.

Reserving the name *gabbro* for those holo-crystalline rocks Case XV. composed of plagioclastic felspar and augite of which the structure is coarsely granitic, it is found convenient to break up the gabbros into four sub-divisions:—

gabbros, olivine-gabbros, enstatite-gabbros and *quartz-gabbros.*

In the first sub-division no other minerals than plagioclastic felspar and augite are present in noteworthy proportion; in

---

* *Tonale,* a mountain on the border of Lombardy and Tyrol.

Case XV. the remaining three, olivine, enstatite or quartz, respectively, is present as an important accessory constituent.

*Norite** is the name given to rocks in which an orthorhombic pyroxene (enstatite) takes the place of the mono-symmetric pyroxene of the gabbros (augite) as an essential constituent; they are differentiated into *norites* and *olivine-norites*, according as olivine is absent or present as an important accessory constituent. The norites are most closely related to the enstatite-gabbros.

The name *dolerite* is now given to rocks, composed of plagioclastic felspar and augite, which may be regarded as structurally intermediate between the gabbros and basalts: the structure is holo-crystalline but is not coarsely crystalline-granular; it is often ophitic. The dolerites are sub-divided in the same way as the gabbros.

Those dolerites which have been pre-Tertiary in their time of formation or intrusive in their mode of origin are regarded by various petrologists as belonging to a distinct kind of rock to which they give the name *diabase;* like some of the remaining dolerites they have an ophitic structure. By reason of their great age and their mode of occurrence, such rocks have suffered more or less alteration.

Teschenites † are closely related to both diorites and dolerites, for in addition to plagioclastic (lime-soda) felspar both hornblende and augite are present as constituent minerals; analcime also enters into the composition.

Proceeding now to the rocks of the rhyolite—basalt group, the felspar of the rhyolites and trachytes is essentially orthoclase (potash-felspar), that of the andesites and basalts is essentially plagioclastic (lime-soda felspar).

---

* Named after Norway.

† *Teschen*, Austrian Silesia.

Rhyolites and trachytes: phonolites: leucite-trachytes.

Taking first the rocks in which the felspar is orthoclase, those which are quartzose or contain the highest percentage of silica, the *rhyolites* or quartz-trachytes, are not sub-divided: on the other hand, the *trachytes* are divided, according to the nature of the ferro-magnesian constituent, into *augite-trachytes, hornblende-trachytes, mica-trachytes,* and *mica-hornblende-trachytes.* Case XII. Case XIII.

Restricting the simple term *phonolite* to those rocks in which a felspathoid takes the place of part of the felspar of trachyte and the felspathoid is essentially nepheline, the composite term *leucite-phonolite* (or leucitophyre) has been applied to similar rocks in which the felspathoid is partly nepheline and partly leucite, while the allied rocks in which the felspathoid is wholly leucite have been designated *leucite-trachyte.*

Andesites.

Passing to those rocks of the rhyolite—basalt group in which the felspar is plagioclastic, the term *andesite* has been extended to include rocks in which the ferro-magnesian constituent is one or more of the minerals augite, enstatite, hornblende or mica; the more prominent kinds being designated:—*augite-andesites, enstatite-andesites, augite-enstatite-andesites, hornblende-andesites* and *mica-andesites.* Case XIV.

Some quartzose rocks are related to andesites in the same way as rhyolites to trachytes and are termed *quartz-andesites* or *dacites.*[*]

Basalts: tephrites and basanites: nephelinites and leucitites.

In the first place, as regards the rocks at the basaltic end of the rhyolite—basalt group, it is found convenient to distinguish Cases XV and XVI.

---

[*] *Dacia,* an ancient Roman province, included the modern Transylvania.

Cases XV and XVI.

basalts and *olivine-basalts*, according as olivine is absent or is present as an additional constituent. In the next place, having regard to the way in which in the phonolites and allied rocks a felspathoid plays the part of a felspar, we may expect a similar differentiation among the basaltic rocks; and, in fact, still reserving the simple term basalt for those in which no felspathoid occurs, other rocks, of which both a felspar and one or more felspathoids are constituents, have been designated *tephrites** or *basanites* † according as olivine is absent or present: the tephrites thus corresponding to basalts, and the basanites to olivine-basalts. According to the nature of the felspathoid, the tephrites are severally distinguished as *leucite-tephrites*, *nepheline-tephrites* or *leucite-nepheline-tephrites*, and the basanites as *leucite-basanites* or *nepheline-basanites.* Where, on the other hand, the felspathoid completely replaces the felspar, the rocks are termed (1) if olivine is absent, *leucitites* or *nephelinites*, according as the felspathoid is leucite or nepheline, and (2) if olivine is present, *leucite-basalts*, *nepheline-basalts* or *melilite-basalts*, according as the felspathoid is leucite, nepheline or melilite.

The mutual relations of these rocks are best seen from the following table:—

Felspar or Felspathoid.	*No olivine.*	*With olivine.*
Felspar only.	Basalt.	Olivine-basalt.
Felspar and felspathoid.	Tephrite.	Basanite.
Felspathoid only.	Leucitite. Nephelinite.	Leucite-basalt. Nepheline-basalt. Melilite-basalt.

A class of rocks, each of them characterised by a groundmass of very fine texture in which no glassy constituents are recognisable and through which crystals are porphyritically dispersed, demands special consideration; it may be *certain* that the structure of a rock is porphyritic even if in some cases it remains doubtful whether the ground-mass is holo-crystalline or mero-crystalline in character.

---

* *Tephros*, ash-coloured.

† Word used by Pliny.

Felsites: minettes and kersantites: porphyries and porphyrites.

In some of the *quartz-felsites*, the ground-mass is of so fine a texture that to resolve it is beyond the power of the microscopist, and none of its constituent matter can be proved to be entirely without action on transmitted polarised light; it is equally impossible to prove that the constituent matter is wholly crystallised. In fact, as regards the true nature of the ground-mass, there is still controversy: by some, the ground-mass is held to be possibly a definite chemical compound and thus a simple mineral species; by others an intimate mixture of extremely fine particles of quartz and orthoclase, from which it is chemically indistinguishable; the felspathic material thus corresponding to an alkali-felspar, not to a lime-soda felspar. Case XII.

It can be proved that in some cases felsite has resulted from the alteration of a vitreous rock which was spherulitic or perlitic before the alteration began, and it is inferred that in many other cases rocks in which no glassy material is now recognisable may once have been mero-crystalline in structure. On the other hand, some of the quartz-felsites have doubtless attained their present characters, not by slow alteration of an already formed rock, but as the result of the comparatively quick cooling of a molten mass near its boundary or in its thinner portions.

In the *minettes** and *kersantites*,† mica (biotite) is porphyritically distributed through a felspathic ground-mass of fine texture: in composition they are related to the syenites and diorites respectively, the felspathic constituent of the ground- Cases XIII and XIV.

---

* *Minette*, a local term.

† *Kersanton*, a hamlet near Brest in Brittany.

mass being orthoclase (potash-felspar) in the minettes and plagioclastic (lime-soda-felspar) in the kersantites. The *camp-* Case XIV. *tonites* * are closely related to both kersantites and porphyrites: the ground-mass is rich in the iron-magnesium minerals (hornblende, some augite, a little biotite); its felspathic constituent is plagioclastic (lime-soda) felspar; the porphyritic crystals are mostly hornblende.

Cases XIII and XIV. Various kinds of rocks belonging to this porphyritic class have been termed *porphyry* and *porphyrite*, the term *porphyry* being often used for the porphyritic rocks which have a percentage chemical composition approximating to those of granites and syenites and a ground-mass of which the felspathic constituent is a potash-felspar, and the term *porphyrite* for those which have a percentage chemical composition approximating to those of diorites and gabbros and a ground-mass of which the felspathic constituent is a lime-soda felspar. A quartzose division of the porphyries, in which quartz is porphyritically developed, is nearly identical with that of the quartz-felsites; a quartz-less division, in which quartz is not porphyritically developed, includes various rocks chemically allied to syenite; among them are rocks which have been termed *orthoclase-porphyries*, *rhomb-porphyries* and *keratophyres*. It has already been mentioned that the porphyries of the former division (*quartz-porphyries*) have been formed in more than one way, and it is quite possible that this may also be true of the quartz-less porphyries.

Both the porphyries and the porphyrites have been subdivided and named according to the species of the pre- Case XIV. dominant porphyritic minerals: for instance, the "antique porphyry" from Egypt is termed *hornblende-porphyrite*. It has been demonstrated that some of the masses which have been named porphyrite have resulted from the alteration of an already formed rock of the rhyolite—basalt group (andesite), and it is possible that in the porphyrites, as in the felsites, the same kinds of lithical characters may have resulted in more than one way.

---

* *Campton*, New Hampshire, U.S.A.

Other rocks allied to the above class and having characters which may have resulted from alteration.

Although, as far as possible, the discrimination of rocks into kinds and the assignation of names should relate to present characters and be independent of uncertain inferences as to the history of the masses, it is convenient to bring near together in the system of classification those kinds which may, in some of their members at least, have a historical relationship: to bring near together, for example, the quartz-felsites, rhyolites and obsidian, and also the porphyrites and andesites, although *all* quartz-felsites have not once been rhyolites or obsidian, and *all* porphyrites have not been andesites.

And, in the same way, there are various rocks which have characters such as might result from the gradual alteration of gabbro, dolerite or basalt, and which may thus be associated with those rocks in the scheme of classification. In some crystalline-granular rocks composed of plagioclastic felspar and pyroxene, the latter constituent is diallage and has characters which might result from the alteration of augite: such a rock has been termed a *diallage-gabbro.* If the felspar **Case XV.** is much altered, the rock is termed a *saussuritic gabbro* or *euphotide* (Haüy); a kind already mentioned, but to which no place in the last-mentioned scheme of classification has been hitherto assigned. *Troctolite* * is the name given to an altered rock allied to olivine-gabbro; serpentinised olivine appears as dark green spots in a grey felspathic ground-mass and the pyroxenic constituent (diallage) is at most in small proportion.

Similarly, the name of *melaphyre* † has been given to rocks which have characters such as may have resulted from the alteration of basalt.

A mass of *serpentine,* again, has characters which indicate **Case XVII.** that it is a result of alteration of an antecedent mass of other rock, which, in most cases was rich in olivine: it may thus, though itself essentially simple, be associated in the scheme of classification with those composite felspar-less rocks, the peridotites, which contain olivine in considerable proportion.

---

* *Troktes,* a sea-fish: from which the word *trout* is derived.

† *Melas,* black; *phyr,* part of the word porphyry.

Case XI. Similarly, *luxullianite* and *trowlesworthite*,* *greisen* and *schorl-rock*, may be ranged near the granites as having characters such as might result from the alteration of that kind of rock.

Though the degree of alteration of a rock is not directly dependent on the length of time which has passed since its formation, a much altered rock is often a correspondingly old one, and the correspondence between age and alteration may be expected to be more close when the alteration is of such a kind that long-continued action is requisite for its development.

Clays and shales: slates.

Cases XIX and XX. Clay, as already stated, is plastic when mixed with water. If the clay is impure through admixture with other minerals, its plasticity is diminished owing to the separation of the particles of clay from each other by the foreign matter. Further, the partial loss of the chemically combined water will cause the material to be no longer clay and thus no longer plastic: if the loss be not uniform throughout the mass, the degree of plasticity of the material will depend on the relative amounts of the altered and unaltered clay.

Some shales, though rendered hard and fissile by the long-continued pressure of the superincumbent material, are so little altered as regards the nature of their constituent particles that they still become plastic when crushed to powder and mixed with water, and are used on a large scale for the manufacture of bricks and tiles.

On the other hand, the exposure of clay to the action of heat or to an enormous thrust may cause the loss of some of the chemically combined water or the formation of new mineral constituents by a process of molecular interchange: we must therefore be prepared to recognise that material now neither plastic when mixed with water nor consisting of simple hydrated aluminium silicate may yet have once been common clay.

---

* *Luxullian* and *Trowlesworthy Tor* are the names of Cornish localities.

Common clay, being a mixture, is incapable of precise definition; further, it is liable to alteration and loss of plasticity: hence, any rock-mass of sedimentary origin and impalpably fine grain, and containing much silica and alumina in its composition, has been inferred to have been once a clay and has been called a *clay-rock* or *argillaceous rock*, even if the material is not now plastic when ground to powder and mixed with water. It has thus come about that the term clay has been used as part of the composite name of the kinds of some rock-masses from which in their present condition true clay is completely or almost completely absent; there is little clay, for example, in most of the rock-masses called *clay-slate.*

It has been already mentioned that some slates were originally deposits of volcanic dust, not clay.

Crystalline schists: phyllites: argillaceous schists.

Cases XVIII and XIX.

As we have seen, a rock of holo-crystalline structure consists of imperfectly developed but almost wholly unbroken crystals in direct contact with each other, and therefore mostly interlocked; a directional arrangement of the constituents, however it may have been produced, may give a foliate character to the structure, and the rock is then termed a *crystalline schist,* for example, mica-schist.

On the other hand, a rock of fragmental structure consists largely of broken constituents cemented together by finer material, which is sometimes of a nature difficultly determinable: such a rock may have laminar fissility and be, for example, a *shale.*

Again, we have seen that an argillaceous sedimentary rock may be mechanically and chemically altered; it may thus become cleavable, and at the same time new crystallised constituents may be developed by molecular interchange, the rock thus becoming a *clay-slate.* It is conceivable that the development of mica along the planes of either cleavage or lamination may advance so far that an argillaceous sedimentary rock may become a mica-schist, the original fragmental structure disappearing and a foliate holo-crystalline structure taking its place.

In fact, many rock-masses have characters intermediate between the two extremes, and, for instance, cannot be definitely distinguished in kind from either clay-slate or mica-schist; they are sometimes termed *argillaceous schists*. In some of these intermediate rocks, the *phyllites*, a surface obtained by splitting has a micaceous lustre due to the secondary development of fine scales of mica along the planes which are now planes of fissility. In the case of the argillaceous schists of the Scottish Highlands, the fissility is parallel to the original sedimentary layers.

Difficulties of classification and nomenclature.

The difficulties involved in the distribution of rocks into kinds, in the assignation of names to the kinds, and in the framing of a natural system of classification will now be more obvious to the student. In the present state of petrological knowledge, these difficulties have not been completely resolved, and it seems best to adopt in the meantime such a partial solution as is indicated above: that is to say, to distribute rocks into kinds defined solely by means of actual characters and without regard to mere hypotheses, to disregard mere hypotheses in the nomenclature of the kinds, to select a limited number of masses of rock of different kinds for use as types, to describe all other masses by comparison of their characters with those of the types, to employ a mixed scheme of classification of the kinds, partly natural and partly artificial, and to have regard in that scheme of classification not only to mineral (and therefore chemical) composition and to structure, but also indirectly, by the assignation of the appropriate degrees of importance to the various lithical characters, to the modes of origin of the rocks. As further knowledge of rocks is attained, the artificiality will gradually disappear from the scheme of classification.

The rocks shown in the cases.

The specimens exhibited in illustration of the various kinds of rocks are arranged in the window-cases as follows:—

Granites (Cases XI and XII).
    Greisens and schorl-rocks.
Granite-porphyries.
Quartz-felsites and felsites (quartz-porphyries).
Rhyolites.
Vitreous representatives (obsidians: pitchstones).

{Syenites (Case XIII).
{Nepheline-syenites.
Minettes.
Syenite-porphyries, orthoclase-porphyries, rhomb-porphyries, keratophyres.
{Trachytes.
{Phonolites (leucite-phonolites or leucitophyres).
Vitreous representatives of the above.

Diorites and quartz-diorites (Case XIV).
Kersantites and camptonites.
Porphyrites.
Andesites and dacites.
Vitreous representatives of the above.

Gabbros (Cases XV and XVI).
    Troctolites.
    Euphotides.
Norites.
Teschenites.
Dolerites (including "diabases").
Basalts.
    Melaphyres.
Basanites and tephrites.

Nephiline-basalts and leucite-basalts.
Nephelinites and leucitites.
Limburgites and augitites.
Vitreous representatives of the above.

Dunites (Case XVII).
Saxonites.
Lherzolites.
Picrites.
Serpentines.

Gneisses: crystalline schists (Cases XVIII and XIX).
Slates.

Tuffs (Case XX).
Breccias.
Conglomerates.
Sandstones.
Clays and shales.

{Limestones (Case XXI).
{Dolomites.
Marls.

Coals (Table-case 41).

INDEX.

The first numerals refer to the pages of the Introduction.

The Roman numerals indicate the window-cases in which the illustrative specimens are shown.

CASE

Abnormal constituents, 62
Absorptive capacity, 42
Accessory constituents, 62
Aggregates, irregular, 13
Aggregate structure, 32, 34, 36
Amorphous, 7, 11, 17
Amphiboles, 101
Amygdaloidal, 42
Andesite, 69, 79, 82, 92, 105 XIV
Anthracitic coal, 2
Antique porphyry, 33, 108 . XV
Aplite, 58, 63, 102 . . . XI
Argillaceous rock, 111 . . XX
Argillaceous schist, 112 . . XIX

Basalt, 69, 79, 82, 88, 96, 105 . . . . . XV, XVI
Basanite, 106 XVI
Boundary of a rock, 17, 52
Breccia, 36, 37, 72, 79, 81 . XX
Brecciate structure, 36

Calcite-rock, 66, 77, 80 . . XXI
Camptonites, 108. . . . XIV
Cellular, cellularity, 41, 84, 90
Cementing material, 38
Chalk, 67, 80. XXI

CASE

Chemical composition, 47, 70, 94
Clastic structure, 36
Clay, 3, 38, 68, 78, 81, 110. XX
Clay-rock, 111 XX
Clay-slate, 43, 111 . . . XIX
Cleavage, 43, 76
Cleveland dyke, 3
Coal, 2, 67, 78, 80, 87
Coherence, 46
Colour, 47
Compact, 46
Conglomerate, 37, 72, 79, 81 XX
Constituents, 26
Crumbly, 46
Crypto-crystalline structure, 41
Crypto-felsitic structure, 41
Crystalline-granular, 38
Crystalline schist, 66, 75, 81, 99, 111. . . . XVIII, XIX
Crystalline structure, 33, 34, 35, 38
Crystallised condition, 17
Crystals, 11, 15

Dacite, 105 XIV
Diabase, 104 XV

CASE
Diorite, 71, 79, 82, 103 . . XIV
Dip, 48
Ditroite, 103 XIII
Divisional planes, 51
Dolerite, 71, 79, 82, 96, 104. XV
Dolomite-rock, 66, 77, 80 . XXI
Dunite, 77, 99 XVII
Dyke, 53

Earthy, 46
Elæolite, 102
Elasticity, 45
Enclosures in constituents, 29
Essential constituents, 62
Euphotide, 71, 79, 82, 96, 109. XV

Faulting, 49
Felsite, 94, 97, 107, 109. . XII
Felsitic structure, 41
Felspathoids, 98
Felstone, 68, 79, 82, 94 . . XII
Fissility, 43
Flexibility, 45
Flexible sandstone, 45
Flow-structure, 38, 40, 49
Foliate structure, 39
Foyaite, 103 XIII
Fracture, 45
Fragmental structure, 36
Frangibility, 46
Friable, 46

Gabbro, 96, 103, 109. . . XV
Glass, 10, 12, 15
Globulites, 14
Gneiss, 66, 76, 81 . . . XVIII
Granite, 3, 5, 18, 39, 46, 57, 63, 71, 79, 82, 92, 102 . XI
Granite-porphyry, 102 . . XII
Granitic structure, 41

CASE
Granitoid structure, 39
Granulitic structure, 40
Graphic granite, 39, 58 . . XI
Greisen, 110 XI
Greystones, 70
Grit, 38 XX
Ground-mass, 33

Hæmatite-rock, 66, 77, 80
Haplite, 58, 63, 102 . . . XI
Hardness, 45
Hemi-crystalline structure, 35
Holo-crystalline structure, 35, 38
Homogeneous structure, 33

Immediate constituents, 26, 46
Individuality, 20
Irregular aggregates, 13

Joint-planes, 51

Keratophyre, 108 . . . XIII
Kersantite, 107 XIV

Laccolite, 53
Lamination, 43
Lapilli, 37
Lava, 21, 23, 72, 79, 83, 84, 90
Lenticular shapes, 53
Leucite-basalt, 106 . . . XVI
Leucitite, 106 XVI
Leucitophyre, 105 . . . XIII
Lherzolite, 99 XVII
Lignite, 4
Limestone, 4, 67, 80. . . XXI
Lithical characters, 25
Longulites, 14
Luxullianite, 110. XI

CASE
Marble, 6, 67, 74, 80 . . . XXI
Melaphyre, 109 XV
Melilite-basalt, 106 . . . XVI
Mero-crystalline structure, 35
Miascite, 103 XIII
Micro-crystalline structure, 38
Micro-felsitic structure, 41
Minette, 107 XIII
Modes of origin, 20, 75, 88, 92, 94, 99
Monzonite, 102 XIII

Napoleonite, 40 XIV
Nepheline-basalt, 106 . . XVI
Nepheline-syenite, 102 . . XIII
Nephelinite, 106 XVI
Norite, 104 XV
Normal constituents, 62

Obsidian, 6, 68, 78, 83, 94, 96 XII
Oolitic structure, 36
Ophite, 39 XV
Orbicular structure, 40
Organisms, 29, 50
Orthoclase-porphyry, 108 . XIII

Pegmatic structure, 39
Peridotite, 99. XVII
Perlicity, 41
Perlitic, 42
Petrical characters, 25, 48
Petrical individuality, 20
Phonolite, 45, 68, 79, 82, 98, 105. XIII
Phyllite, 112 XIX
Picrite, 99 XVII
Pisolitic structure, 36
Pitchstone, 5 XII
Plutonic, 94
Porosity, Porous, 41, 42

CASE
Porphyrites, 33, 108 . XIV, XV
Porphyritic pitchstone, 5 . XII
Porphyritic structure, 33, 34
Porphyry, 33, 108 . . . XIII
Principal constituents, 62
Pumice, Pumiceous, 41 . . XII
Pyroxenes, 101

Quartz-andesite, 105. . . XIV
Quartz-diorite, 103 . . . XIV
Quartz-felsite, 94, 97, 107, 109. XII
Quartz-porphyry, 108 . . XII
Quartz-rock, 66, 77, 80 . . XX
Quartz-trachyte, 70, 105 . XII

Rhomb-porphyry, 108 . . XIII
Rhyolite, 70, 79, 82, 92, 97, 105. XII
Rock defined, 3.
Rock-salt, 66, 77, 80

Sand, 3, 37
Sandstone, 37, 45, 72, 79, 81 XX
Saussuritic gabbro, 96, 109 XV
Saxonite, 99 XVII
Schist, 66, 75, 81, 99, 111, 112. . . . . XVIII, XIX
Schistose structure, 39, 41
Schorl-rock, 110 XI
Semi-crystalline structure, 35
Serpentine-rock, 60, 66, 77, 80, 86, 109 XVII
Shale, 66, 76, 81, 110, 111 . XX
Shell-limestone, 4 . . . XXI
Sill, 53
Slate, 66, 76, 81 XIX
Specific gravity, 47
Spherulitic structure, 41
Strike, 48
Structural planes, 51

CASE
Structure, 32
Subordinate constituents, 62
Syenite, 71, 79, 82, 102 . . XIII
Syenite-porphyry, 113 . . XIII

Tachylyte, 96 XVI
Tephrite, 106 XVI
Teschenite, 104 XV
Texture, 32
Tonalite, 103. XIV
Tourmaline-granite, 57 . . XI
Trachyte, 69, 79, 82, 92, 105 XIII
Trachytic structure, 41
Troctolite, 109 XV
Trowlesworthite, 110 . . XI
Tuff, 37 XX
Types, 72

CASE
Ultrabasic, 99

Vesicular, 41
Vitreous structure, 34, 41
Volcanic agglomerate, 37 . XX
Volcanic bomb, 37
Volcanic breccia, 37 . . . XX
Volcanic dust, 37
Volcanic lapilli, 37
Volcanic tuff, 37 XX

Weathering, 49, 86

Zircon-syenite, 103 . . . XIII

THE END.

LONDON: PRINTED BY WM. CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

BRITISH MUSEUM (NATURAL HISTORY)

CROMWELL ROAD, LONDON, S.W.

GUIDE-BOOKS.

A General Guide to the British Museum (Natural History). 2 Plans and 2 Views. 8vo. 3*d.*

Zoological Department.

Guide to the Galleries of Mammalia. 57 Woodcuts and 2 Plans. 8vo. 6*d.*

———— Reptiles and Fishes. 101 Woodcuts and Plan. 8vo. 6*d.*

———— Shell and Star-fish Galleries. 51 Woodcuts and Plan. 8vo. 4*d.*

Geological Department.

Guide to the Fossil Mammals and Birds. 119 Woodcuts and Plan. 8vo. 6*d.*

———— Fossil Reptiles, Fishes and Invertebrates. 94 Woodcuts and Plan. 8vo. 6*d.*

———— Fossil Fishes. 81 Woodcuts. 8vo. 4*d.*

Mineralogical Department.

Guide to the Mineral Gallery. Plan. 8vo. 1*d.*

Student's Index to the Collection of Minerals. 8vo. 2*d.*

Introduction to the Study of Minerals, with a Guide to the Mineral Gallery. 41 Woodcuts and Plan. 8vo. 6*d.*

———— Study of Rocks. Plan. 8vo. 6*d.*

———— Study of Meteorites, with a List of the Meteorites represented in the Collection. Plan. 8vo. 6*d.*

Botanical Department.

Guide to Sowerby's Models of British Fungi. 93 Woodcuts. 8vo. 4*d.*

The Guide-books can be obtained only at the Natural History Museum, *Cromwell Road, London, S.W.* Written communications respecting them should be addressed to *THE DIRECTOR.*

CR.